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A STUDY OF THE VARIABLES ENTERING INTO THE PRODUCTION OF MALLEABLE IRON

By

EMIL LEO LEASMAN

****

A Thesis Submitted for the Degree of

CHEMICAL ENGINEER

UNIVERSITY OF WISCONSIN

1913

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PART II

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PART I

INTRODUCTION

A. History and Early Developement of the Industry.

B. Present Importance of the Industry.

C. Present Industrial Practice.

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PART I

INTRODUCTION

A

History and Early Developement of Industry

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HISTORY AND EARLY DEVELOPEMENT

The present developement of the malleable iron industry has reached large proportions, approximating one million tons per year. Although this tonnage has reached such large proportions, the technique of the industry has advanced but little.

Moldenke[1] in his book states,- " No branch of the iron industry has experienced so little change from early methods as the production of malleable castings."

The first record we have of this industry is by Reaumur[1] in 1722, but patents were issued to Lucas in 1804, and to Brown and Lennox some fifty years later. Wit hout doubt the malleablizing process was conducted in the same manner from the earliest times, and the secrets of the process were handed down from father to son.

The pioneer manufacturer of malleable castings in the United States[1] was Seth Boyden of Newark, New Jersey. Although he did not solve the underlying principles involved, yet his recorded experiments are the first we have and he deserves special credit inasmuch

---

1 Richard Moldenke , The Production of Malleable Castings.

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as they were made at a time when scientific experiments on industrial problems were frowned upon.

From the earliest times, the manufacturer of malleable iron exercised the greatest secrecy lest the secrets of his work should become known t o his competitors and the public. The melter of a malleable works was the czar of the plant, and the owners were entirely at his mercy.[1] Moldenke states,- " So much so were the owners in the hands of their melters that the latter always became partners in the end, and only then considered the interests of the works before their own."

As the industry stands today, it is furthest advanced in the United States.[1] Moldenke states,- " Perhaps to one man more than any other of the self made men of America, William McConway of Pittsburgh, is due the credit for the great change in the industry." It was he who in the eighties supported the scientific study of the process, and the knowledge thus obtained was carried by men who went from shop to shop. Due to the spreading of this information, and the lifting of the veil of secrecy from the process, the practice and methods of the process were revolutionized. Enough has been learned to enable a foundry to turn out

---

1 Richard Moldenke, The Production of Malleable Castings.

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a good product regularly, although the scientific principles underlying the process are known but to a very few, and the research laboratories investigating these principles may be counted on the fingers of one hand.

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PART I

INTRODUCTION

B

Present Importance of the Industry

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PRESENT IMPORTANCE OF INDUSTRY

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[1] The annual production of malleable castings at the close of the first decade of the twentieth century is about one million tons for the world. Of this tonnage, America produces nine tenths. In Europe, Germany leads, with England second, while France, Italy and Sweeden are small producers.

[2] Malleable iron occupies a position between ordinary cast iron and steel. It has a higher tensile strength than cast iron but not so high as that of steel, while it's resilience is superior to either.

Malleable castings are largely used in railroad equipment because of this property of high resilience. They are also largely used in agricultural implements, pipe fittings, hand tools, stoves, etc. Where large numbers of small, malleable castings are required, this industry has a monopoly of the business.

---

1 Richard Moldenke, The Production of Malleable Castings.

2 James Aston, Wisconsin Engineer XVI, 8:341

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PART I

INTRODUCTION

Present Industrial Practice

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PRESENT INDUSTRIAL PRACTICE

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1 The present method of producing malleable castings is fairly general and uniform throughout the country. The white iron castings are packed in rolling mill scale, and rectangular cast iron boxes are used for the containers. These containers are then luted over with fire clay in order to make them as tight as possible, and are placed in tiers in large brick furnaces. After the doors of the furnaces have been bricked up, the whole is brought up to the desired temperature, and kept there for two or three days. The time consumed in again cooling the furnace so that the charge may be removed also requires from two to three days. The total time required to produce a good product of malleable iron averages about a week - from the time of making the charge to the time of dumping the pots.

After the castings have been dumped, they cleaned, inspected and sorted, and are ready for shipment.

---

1 Richard Moldenke, The Production of Malleable Castings.

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PART II

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PART II

THE MALLEABLIZING PROCESS

A. The Metallography of White Cast Iron.

B. The Theory of the Malleablizing Process.

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PART II

A

The Metallography of White Cast Iron.

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THE METALLOGRAPHY OF WHITE CAST IRON

The white cast iron used for the manufacture of malleable iron must be of suitable composition for such work, and will have a micro-structure which is similiar to the ordinary grade of white iron. The accompanying micrographs on page 15-C illustrate the structure of such white iron. The particular sample used for these micrographs is from the Beaver Dam Malleable Iron Works of Beaver Dam, Wisconsin, and is representative of the material used in the following experiments.

Figure 3-P shows a typical white cast iron structure. The white areas represent the iron carbide, or Cementite, which was not attacked by the etching reagent, Picric Acid. The dark areas are Pearlite and are composed of plates of Cementite and Ferrite. The general structure of Figure 7-A and 4-A is the same, but there being more white areas in 7-A shows that a larger percentage is present.

Figure 3-P was taken from a sample which contained steel scrap in the white iron charge. It shows a different structure than that of the other two samples; the areas of Pearlite being round in form. Also, the white areas are not as prominent showing

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that there was not as much carbon present. This is to be expected as steel scrap is generally added to the white iron melt to cut down the percentage of carbon in the white iron casting.

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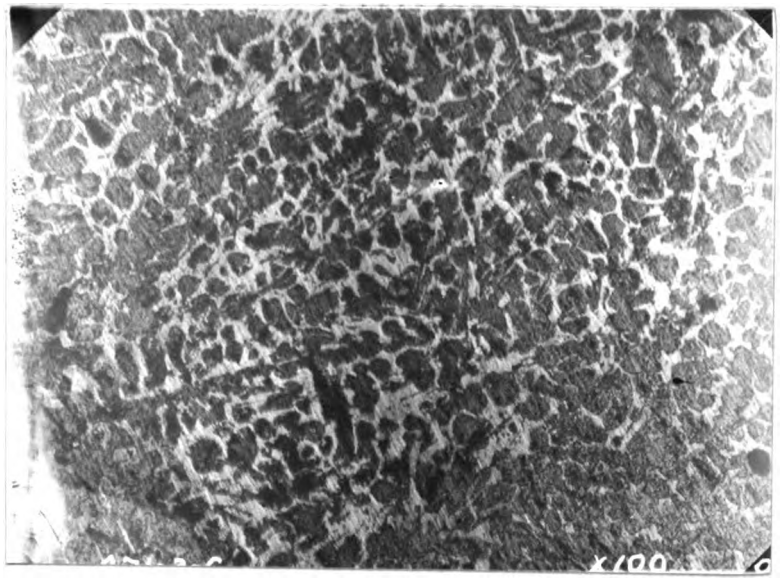

Figure 3-P

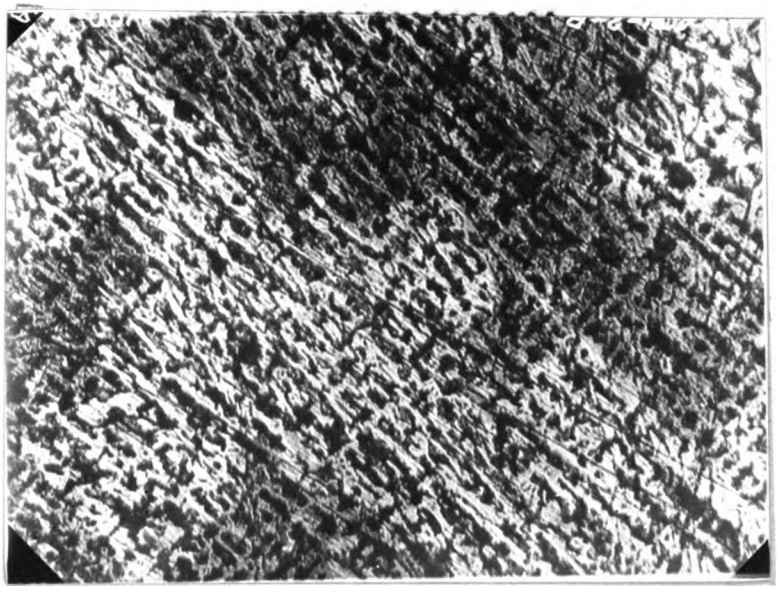

Figure 7-A

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MICROGRAPH OF WHITE IRON

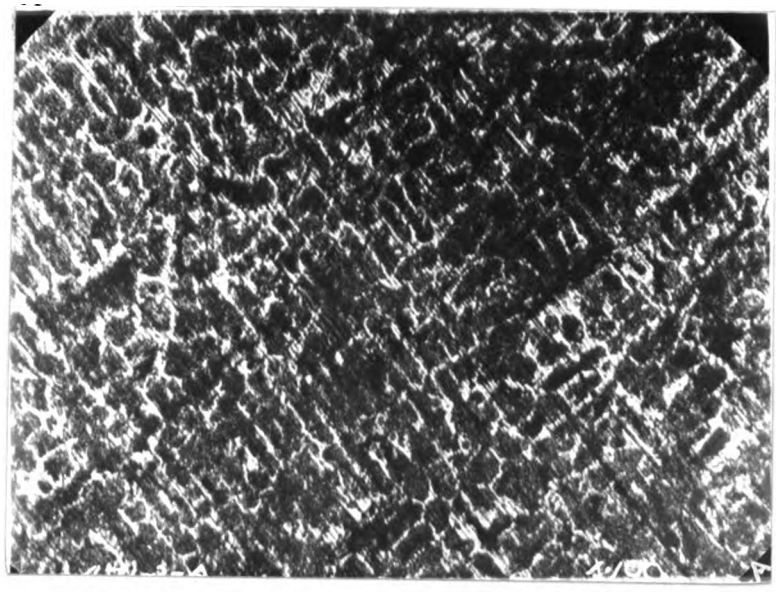

Figure 4-A

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PART II

B

THE THEORY OF THE MALLEABLIZING PROCESS

1. Proper stock of white iron and it's chemical analysis.

2. The effect of heat treatment.

3. The metallography of malleable iron.

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PROPER STOCK

The stock used in this process is white cast iron; an iron having the iron and carbon combined as Cementite or Iron Carbide. A chemical analysis of such white iron follows,-[1]

Carbon	about 3.00%
Silicon	0.50 to 1.0%
Sulphur	below 0.08%
Phosphorus	below 0.225%
Manganese	0.25 t o 0.50%

Cast iron is a complex alloy of iron with carbon and the other elements above listed. The state of the carbon is of the most importance and the other elements are secondary and influence the state of the carbon. Carbon is associated with iron in three different states, namely,- As a definite carbide known as Cementite, with the formula Fe_3C ; as free carbon or graphite; and as a solid solution of carbon or combined carbon (carbide) in iron.

Of the secondary elements, Silicon exerts the greatest influence on the state of the carbon, and tends t o form graphitic carbon. Sulphur and Manganese tend

---

1 James Aston, Wisconsin Engineer, XVI, 8 : 341

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to form combined carbon. In the casting of white iron, the silicon content is so controlled that it's influence during the cooling of the casting will not be great enough to precipitate out the carbon as free graphite, but allow it t o remain in the combined form as iron carbide.

---

3. EFFECT OF HEAT TREATMENT

When white iron is heated sufficiently, the Cementite, both the excess and that present in the eutectoid, is broken down into it's constituents of iron and carbon, according to the reaction,-

$$Fe_3C = 3\,Fe + C$$

This change may result from a high heat for a short period of time, or from a lower heat for a longer period of time.

The temperature and time necessary to effect this change depends upon the composition of the white iron. The three elements which will determine these efffects are,- Silicon, Manganese and Sulphur. The Silicon will tend to lower the temperature since this element prevents the formation of combined carbon. By increasing the Manganese content, the temperature must be raised since it tends to keep the carbon in the

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combined form. Sulphur also has tendency to exert the same influence.

Not only must the temperature be high enough and the time long enough to break down the Cementite in the white iron, but the material must be cooled slowly or a steely structure will result.

When cast iron is properly malleablized, the carbide is entirely broken down into it's elements, and the carbon is precipitated out as globules of amorphous carbon, surrounded by pure Ferrite. Carbon in this form is known as Temper Carbon & does not occur in flakes as in grey cast iron.

---

3. METALLOGRAPHY OF MALLEABLE IRON.

The accompanying micrograph on page 31 shows the interior structure of malleable iron. The white field is Ferrite and the dark spots are particles of Temper Carbon.

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Micrograph showing the interior structure of typical

MALLEABLE IRON

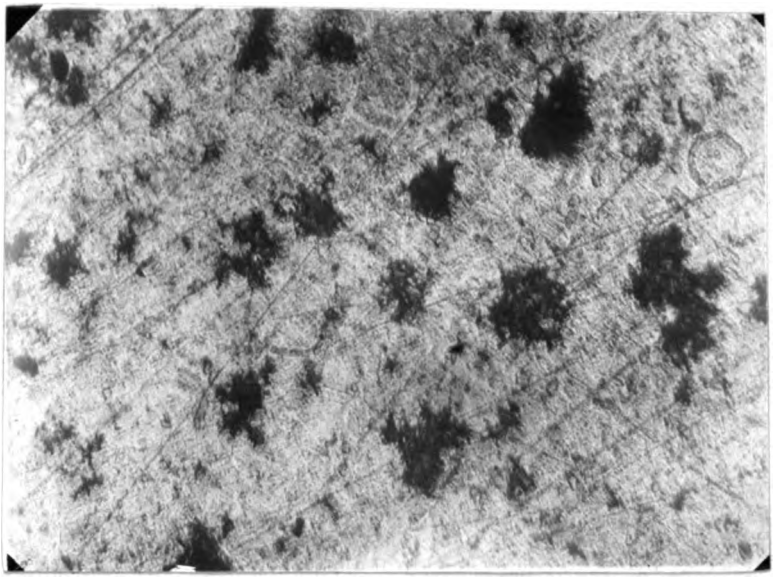

Figure No. 1.

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PART III

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PART III

SCOPE OF THIS THESIS

***

A. Object of the Work.

B. Plan of Attack.

C. Materials and Apparatus Used.

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PART III

****

A

Object of the Work

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1. Very little data is available showing the effects of the variables entering into the malleablizing process, such as,-

1. The effect of different packing materials.
2. The effects of different annealing temperatures.
3. The effects of different times of annealing.
4. The effects of different times of cooling.

This work was undertaken to show the effects of these variables, and is given under PART IV.

---

2. To show what becomes of the carbon which is normally present at the surface of white cast iron and which disappears during the process of malleablizing. It has been held by some that this carbon moves to the interior of the casting, while others claim that the carbon leaves the casting entirely. See PART V.

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PART III

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B

Plan of Attack

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PLAN OF ATTACK

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The work was undertaken according to the following plan,- Having the chemical analysis of the stock white iron as constant, there are five variables entering into the malleablizing process, namely,-

1. Packing materials used.
2. Temperature of annealing used.
3. Time of annealing.
4. Time of cooling.
5. Time of bringing t he furnace and charge up to the heat desired.

The last variable is entirely dependent upon the type of furnace used, and because it is well known that the rate of heating does not effect the resulting malleable structure, the fifth variable does not enter into this work. In the following experiments therefore, only the first four variables will be investigated.

By keeping three variables constant and varying the fourth for any set of experiments, the fourth may be obtained as a constant. This scheme followed to it's logical conclusion should indicate the best conditions for producing malleable iron, and the influence of the different variables.

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P A R T III

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C

Materials and Apparatus Used

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MATERIALS USED

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WHITE CAST IRON

The white iron used was obtained from standard test bars, 3/4" x 3/4" x 10", and were supplied by the Beaver Dam Malleable Iron Works, Beaver Dam, Wisconsin. The chemical analysis as supplied by the company's chemist, Mr. W. G. Grimer, is as follows,-

Combined carbon	2.60 t o 2.70%
Silicon	0.65 to 0.70%
Sulphur	0.55 to 0.60%
Phosphorus	0.14%
Manganese	0.27%

PACKING MATERIALS

The packing materials used consisted of rolling mill scale, and other materials as supplied by the laboratory.

CONTAINERS FOR SPECIMENS

The containers were made of 1 1/2" pipe, cut to length to take specimens about 2" long. These containers were luted shut with fire clay except where pipe nipples and caps were used. The latter will be noted as "Special Box" when used.

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APPARATUS USED

****

FURNACES

The two muffle furnaces used were electric muffles built by the author in the Chemical Engineering Laboratory, and consisted of muffles heated electrically by means of resistance wire.

PYROMETERS

The pyrometers used were couples supplied by the laboratory, and were standardized against a standard Platinum - Platinum-Rhodium Couple.

FURNACE REGULATION

One furnace was controlled by means of a lamp bank in series with the furnace, and was supplied with current from a 110 Volt, Alternating Current Circuit.

The other furnace was on a 220 Volt, Alternating Current Circuit, and the pressure was regulated by means of a low voltage transformer. The current was regulated by means of a lamp bank in series wit h t he primary coil of the transformer.

Both of these methods of control were found satisfactory in every respect.

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PART IV

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PART IV

DATA

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A. Effect of Various Packing Materials.

B. Effect of Different Temperatures of Annealing.

C. Effect of Different Periods of Cooling.

D. Effect of Different Periods of Annealing.

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P A R T IV

***

A

THE EFFECT OF VARIOUS PACKING MATERIALS

I. Constants in t his series of Experiments.

II. Data,

Experiment #1.
Experiment #2.
Experiment #3.

III. Micrographs of Typical Specimens.

IV. Results and Conclusions.

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P A R T IV

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A

I. CONSTANTS * PACKING SERIES

1.	Temperature	=	1600-50° F.
2.	Time of Annealing	=	50 Hours
3.	Time of Cooling to 500 degrees F.	=	50 Hours

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P A R T IV

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II. D A T A * PACKING SERIES.

(a) Experiments Number 1, 2 and 3.

1. Data showing kind of packing used, number of specimen, and conditions of packing material and specimens after annealing.

2. Time - Temperature heating and cooling curves. Chart No. 1.

3. Summation data, and results of microscopic examination of specimens after annealing.

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P A R T IV

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II

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(a) EXPERIMENTS NUMBERS 1, 2 and 3.

****

1. Data showing the kind of packing used; number of the specimen; and conditions of the packing material and specimens after annealing, upon unpacking.

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EXPERIMENT No. 1

Specimen #1, packed in Lime. Fairly heavy scale on specimen; packing adherent but easily removed.

Specimen #2, packed in Sand. Fairly heavy scale on specimen, with sand adherent and colored red.

Specimen #3, packed in Alundum. Specimen surrounded with a hard shell, which was easily removed, and left the specimen clean and colored red.

Specimen #4, packed in Rolling Mill Scale. Fairly heavy, tenacious scale; packing adherent.

Specimen #5, packed in Resister Carbon. Packing not adherent to specimen which had a blue & red color.

Specimen #6, packed in Manganese Dioxide. Specimen and container heavily attacked; specimen covered with a shell about 1/16" thick which was easily removed, and left the specimen clean and blue in color.

Specimen #7, packed in Neat Cement. Packing disintegrated and not adherent.

Specimen #8, NO PACKING. Heavy, tenacious scale formed.

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EXPERIMENT No. 2

Specimen #9, packed in Coarse Fire Clay. Fairly heavy scale; packing adherent.

" #10, packed in fine Rolling Mill Scale. Heavy scale.

" #11, packed in pure Iron Oxide. Fairly heavy scale; packing adherent and brown in color.

" #12, packed in fine Graphite. Specimen clean; packing hard.

" #13, packed in Alumina. Fairly heavy scale; packing adherent.

" #14, packed in Chromite. Heavy scale; packing adherent.

" #15, packed in Brass Turnings. Packing fused and adherent.

" #1X, No Packing, Specimen at end of furnace. Coated with heavy black scale.

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EXPERIMENT No. 3

Specimen #16, packed in Portland Cement. Fairly heavy scale; packing tenaciously adherent.

" #17, packed in Bauxite. Heavy scale easily removed; packing adherent.

" #18, packed in Hydrated Magnesia. Fairly heavy scale; packing somewhat adherent.

" #19, packed in Fine Fire Clay. Specimen clean; packing hard and pinkish in color.

" #20, packed in ordinary Iron Oxide. Heavy scale; packing adherent and lumpy.

" #21, packed in Carborundum. Thin scale; packing adherent.

" #22, No Packing, standing in center of furnace. Heavy scale formed.

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P A R T IV

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A

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II

****

(a) EXPERIMENTS NUMBERS 1, 2 and 3.

****a

2. Time - Temperature Heating and Cooling Curves

CHART No. 1.

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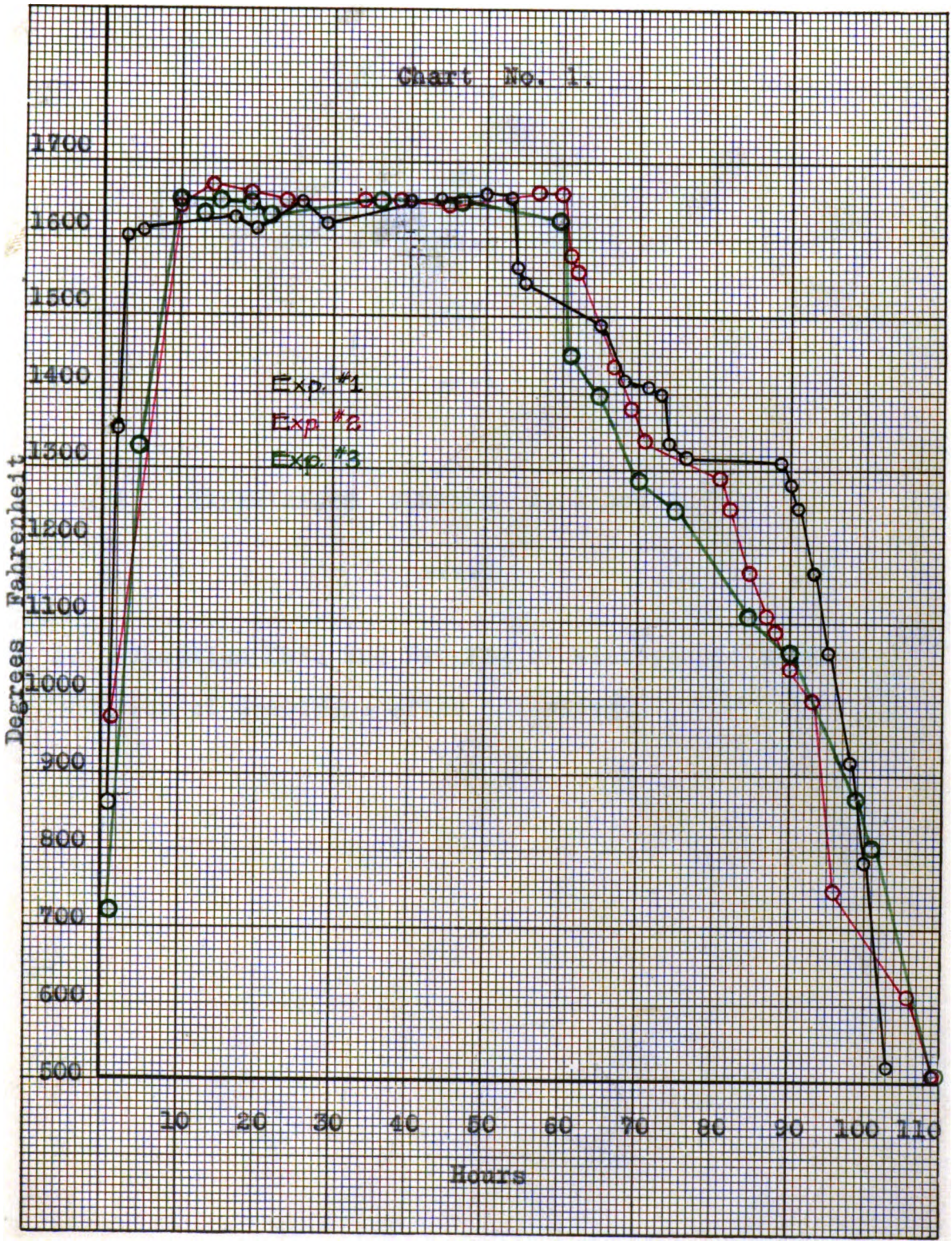

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P A R T IV

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A

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II

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(a) EXPERIMENTS NUMBERS 1, 2 and 3.

*****

3. Summation Data and Results of Microscopic Examination of Specimens after annealing.

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ANNEALING TEMPERATURE OF 1600 - 1650 degrees Fahrenheit;

TIME OF MAINTAINING SAME, 50 HOURS;

TIME OF COOLING TO 500 degrees Fahrenheit, 50 HOURS,

20 hours to 1390°F.
18 hours to 1250°F.
12 hours to 500°F

****

MICROSCOPIC EXAMINATION

Specimen #1, packed in Lime

Edge	Temper Carbon and Ferrite
Center	Temper Carbon " "

Specimen #2, packed in Sand.

Edge	Temper Carbon and Ferrite
Center	Do

Specimen #3, packed in Alundum.

Edge	Thin layer of Ferrite; high Carbon Steel.
Center	Temper Carbon and Pearlite.

Specimen #4, packed in Rolling Mill Scale.

Edge	Ferrite and Pearlite
Center	Temper Carbon and Ferrite.

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Specimen #5, packed in Resister Carbon.

Edge	Ferrite and Pearlite
Center	Temper Carbon; Ferrite and Pearlite.

Specimen #6, packed in Manganese Dioxide.

Edge	Heavy layer of pure Ferrite.
Center	Temper Carbon and Ferrite.

Specimen #7, Packed in Neat Cement.

Edge	Pure Ferrite.
Center	Temper Carbon and Ferrite.

Specimen #8, No Packing.

Edge	Temper Carbon and Ferrite.
Center	Temper Carbon & Ferrite.

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EXPERIMENT No. 2.

*****

ANNEALING TEMPERATURE OF 1650° F. ;

TIME OF MAINTAINING SAME, 50 HOURS;

TIME OF COOLING TO 500 F., 50 HOURS;

9 hours to 1390° F.
13 hours to 1250° F.
28 hours to 500° F.

******

MICROSCOPIC EXAMINATION

Specimen #9, packed in Coarse Fire Clay.

Edge	Ferrite and Pearlite
Center	Low carbon steel and Temper Carbon.

Specimen #10, packed in Rolling Mill Scale.

Edge	Ferrite and High Carbon Steel.
Center	Mild Steel and Temper Carbon.

Specimen #11, packed in pure Iron Oxide.

Edge	Ferrite and High Carbon Stee
Center	Medium Carbon Steel & Temper Carbon.

Specimen #12, packed in Fine Graphite.

Edge	Ferrite and High Carbon Steel.
Center	Medium Carbon Steel and Temper Carbon.

Specimen #13, packed in Alumina.

Edge	Ferrite.
Center	Medium Carbon Steel and Temper Carbon.

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Specimen #14, packed in Chromite.

Edge	Ferrite and Pearlite.
Center	Pearlite and Temper Carbon.

Specimen #15, packed in Brass Turnings.

Edge	Yellow metal and Pearlite.
Center	Pearlite and Temper Carbon.

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E X P E R I M E N T No. 3

****

SAME TEMPERATURE AND PERIOD OF HEATING AS No. 2.

TIME OF COOLING TO 500° Fahrenheit, 50 HOURS.

5 hours to 1390° F.
10 hours to 1250° F.
35 hours to 500° F.

****

MICROSCOPIC EXAMINATION

Specimen #16, packed in Portland Cement..

Edge	Ferrite & Pearlite.
Center	Pearlite & Temper Carbon.

Specimen #17, packed in Bauxite.

Edge	Ferrite & Pearlite.
Center	Pearlite & Temper Carbon.

Specimen #18, packed in Hydrated Magnesia.

Edge	Ferrite & Pearlite.
Center	Pearlite & Temper Carbon.

Specimem #19, packed in fine Fire Clay.

Edge	Ferrite & Pearlite.
Center	Pearlite & Temper Carbon.

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Specimen #20, packed in Iron Oxide.

Edge	Ferrite & Pearlite.
Center	Pearlite & Temper Carbon.

Specimen #21, packed in Carborundum.

Edge	Ferrite & Pearlite.
Center	Pearlite & Temper Carbon.

Specimen #22, No Packing used.

Edge	Ferrite & Pearlite.
Center	Ferrite & Temper Carbon.

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P A R T IV

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A

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III. M I C R O G R A P H S * PACKING SERIES

**

See Figures No. 1, 2, 3, 4, 5,
8, 9, 10, 11, 12.

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IV. RESULTS AND CONCLUSIONS * PACKING SERIES.

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RESULTS AND CONCLUSIONS.

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The results obtained by the use of various packing materials, warrants the conclusion that they have no important effect upon the interior structure of malleable iron. However, it is noticeable that those packings which are not stable at the annealing temperature used, have seemingly been the most active in causing a removal of the carbon from and near the surface of the specimen.

The surface, or skin effect is dependent upon the nature of the packing used, and also upon the method of packing; that is, whether the materials are loosely packed and allow free access of the oxygen in the air. Where an oxidizing packing is used, or where a specimen is loosely packed, the carbon was entirely removed from the outside portion of the specimen.

Where a packing was used which would pack closely about the specimen, such as fine fire clay, the decarbonization took place only to a limited extent. In this case the carbon remained as a Pearlitic structure of varrying thickness. Experiments were run with carbon in various forms (see also Experiments No. 16, 17 and 18) as the packing materials, and a Pearlitic structure generally obtained as a skin effect.

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These experiments resulted in the following conclusion,- The presence of oxygen is necessary for the decarbonization of the surface, and that this oxygen is supplied by the air and finds it's way to the specimen owing to the looseness of the packing material.

These experiments also show that a rapid rate of cooling causes the formation of steel as the interior structure of the specimen.

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PART IV

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THE EFFECTS OF DIFFERENT TEMPERATURES OF ANNEALING.

I. Constants in this series of experiments.

II. Data,

Experiments #4 to 10 inclusive.

III. Micrographs.

IV. Results and Conclusions.

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PART IV

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I. CONSTANTS * TEMPERATURE SERIES.

1. Packing materials, such as fire clay, rolling mill scale, no packing, and several others.

2. Time of Annealing = 50 hours.

3. Time of Cooling = 50 hours.
to 500 degrees F.

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II. DATA * TEMPERATURE SERIES.

(a) Experiments Number 4 to 10 inclusive.

1. Data showing kind of packing used; number of specimen; and conditions of packing material and specimens after annealing.

2. Time - temperature heating and cooling curves. Charts #2, #3 and #4.

3. Summation data and results of microscopic examination of specimens after annealing.

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(a) EXPERIMENTS NUMBER 4 to 10 INCLUSIVE.

1. Data showing the kind of packing used; number of the specimen; and condition of the packing material and specimens after annealing, and upon unpacking.

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EXPERIMENT No. 4

Specimen #23, packed in Resister Carbon. Fairly heavy scale; packing burned to ash.

Specimen #24, packed in Iron Oxide. Thin scale; packing not adherent.

Specimen #25, packed in Sand containing 10% Resister Carbon by volume. Sand tenaciously adherent; fairly heavy scale hard to remove.

Specimen #27, packed in Rolling Mill Scale. Fairly heavy scale; packing caked hard but not adherent.

Specimen #28, packed in Rolling Mill Scale. THIS SPECIMEN HAD PREVIOUSLY BEEN HEATED FOR SEVERAL HOURS AT 1600 DEGREES FAHRENHEIT.

Specimen #29, no packing. Fairly heavy scale.

****

EXPERIMENT No. 5

Specimen #30, packed in Resister Carbon. Thin scale; packing brown in color, and not tenaciously adherent.

Specimen #31, packed in Iron Oxide. Heavy scale; packing blue in color and tenaciously adherent.

Specimen #32, packed in Iron Oxide containing 10% of Resister Carbon by volume. Fairly heavy scale; packing blue in color and tenaciously adherent.

Specimen #33, packed in Fine Fire Clay. Thin scale; packing adherent and yellowish in color.

Specimen #34, packed in Rolling Mill Scale. Fairly heavy scale; packing adherent; specimen red in color.

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Specimen #35, packed in Graphite. PREVIOUS HEATED SPECIMEN.

Specimen #36, Grey Iron packed in Resister Carbon. Fairly heavy scale; packing adherent.

Specimen #37, No Packing. Thin scale; specimen blue in color.

****

EXPERIMENT No. 6.

Specimen #38, packed in Resister Carbon. Packing burned at ash at ends of specimen where a fairly heavy scale was formed. Specimen so hard that saw would only touch the outside.

Specimen #39, packed in Iron Oxide. Packing slightly adherent. Specimen too hard to saw.

Specimen #40, packed in Iron Oxide containing 25% of graphite by volume. Thin scale; packing not adherent. Specimen too hard to saw.

Specimen #41, packed in Rolling Mill Scale with 10% of graphite by volume. Thin scale; packing somewhat adherent. Specimen too hard to saw.

Specimen #42, packed in Rolling Mill Scale. Thin scale. SPECIMEN SOFT ENOUGH TO SAW IN TWO.

Specimen #43, packed in Sand containing 25% of Resister Carbon by volume. Thin scale; packing adherent. Specimen too hard to saw.

Specimen #44, No Packing. Thin scale. Specimen too hard to saw.

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Specimen #45, packed in Rolling Mill Scale. Fairly heavy scale, tenaciously adherent. Specimen too hard to saw.

****

EXPERIMENT No. 7

Specimen #38a, packed in Resister Carbon. Packing burned to ash at ends and slightly adherent. Specimen too hard to saw. This specimen was at end of furnace.

Specimen #39a, packed in Iron Oxide. Thin scale; packing slightly adherent. Specimen too hard to saw. This specimen was at end of the furnace.

Specimen #41a, packed in Scale containing 10% of graphite. Fairly heavy scale; packing adherent. Specimen very hard to saw in two. This specimen at center of furnace.

Specimen #43a, packed in Sand containing 25% of Resister Carbon. Fairly heavy scale with packing adherent. Specimen very hard to saw. This specimen at center of furnace.

Specimen #44a, No packing. Thin scale. Specimen very hard to saw. This specimen at center of furnace.

Specimen #45a, packed in Rolling Mill Scale. Thin scale with adherent packing. Specimen hard to saw. This specimen at end of furnace.

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EXPERIMENT No. 8

Specimen #46, packed in Resister Carbon. Packing burned to ash at ends where it was adherent to specimen. Too hard to saw.

Specimen #47, packed in Iron Oxide. Very thin scale with packing not adherent. Too hard to saw.

Specimen #48, packed in Sand containing 25% Resister Carbon by volume. Thin scale with packing somewhat adherent. Too hard to saw.

Specimen #49, packed in Rolling Mill Scale. Very thin scale with packing slightly adherent. Too hard to saw.

Specimen #50, packed in Rolling Mill Scale. Thin scale with packing somewhat adherent. THIS SPECIMEN HAD PREVIOUS TREATMENT FOR A FEW HOURS. Specimen hard to saw.

Specimen #51, packed in Scale containing 25% of Resister Carbon by volume. Thin scale with packing somewhat adherent. Too hard to saw.

Specimen #52, packed in Chromite. Thin scale with packing not adherent. Too hard to saw.

Specimen #53, No packing. Thin scale. Too hard to saw in two; saw went in about 1/8".

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EXPERIMENT No. 9

Specimen #54, packed in Graphite IN SPECIAL BOX.
No scale with packing not adherent.

Specimen #55, packed in Fine Fire Clay IN SPECIAL BOX.
No scale with packing dark in color and not adherent.

Specimen #56, packed in Graphite. Thin scale with packing burned at ends.

Specimen #57, packed in Rolling Mill Scale. Thin scale with packing adherent and caked.

Specimen #58, packed in Fine Fire Clay. Very thin scale slightly adherent.

****

EXPERIMENT No. 10

Specimen #59, packed in Scale IN SPECIAL BOX.
No scale with packing not adherent.
Too hard to saw.

Specimen #60, packed in Rolling Mill Scale. Fairly heavy scale with packing adherent.
Very hard to saw in two.

Specimen #61, packed in Graphite IN SPECIAL BOX.
No scale with packing not adherent.
Hard to saw in two.

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Specimen #62, packed in Graphite. No scale with packing not adherent..Not easy to saw.

Specimen #63, packed in Fine Fire Clay. Thin scale with packing tenaciously adherent.

Specimen #64, packed in Fine Fire Clay containing 10% of Graphite by volume. Thin scale with packing tenaciously adherent.. Too hard to saw. Specimen at end of furnace.

Specimen #65, No packing. Thin scale. Too hard to saw. Specimen at end of furnace.

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(a) EXPERIMENTS NUMBERS 4 to 1 0 INCLUSIVE.

2. Time - Temperature Heating and Cooling Curves.

Charts #2, #3 and #4.

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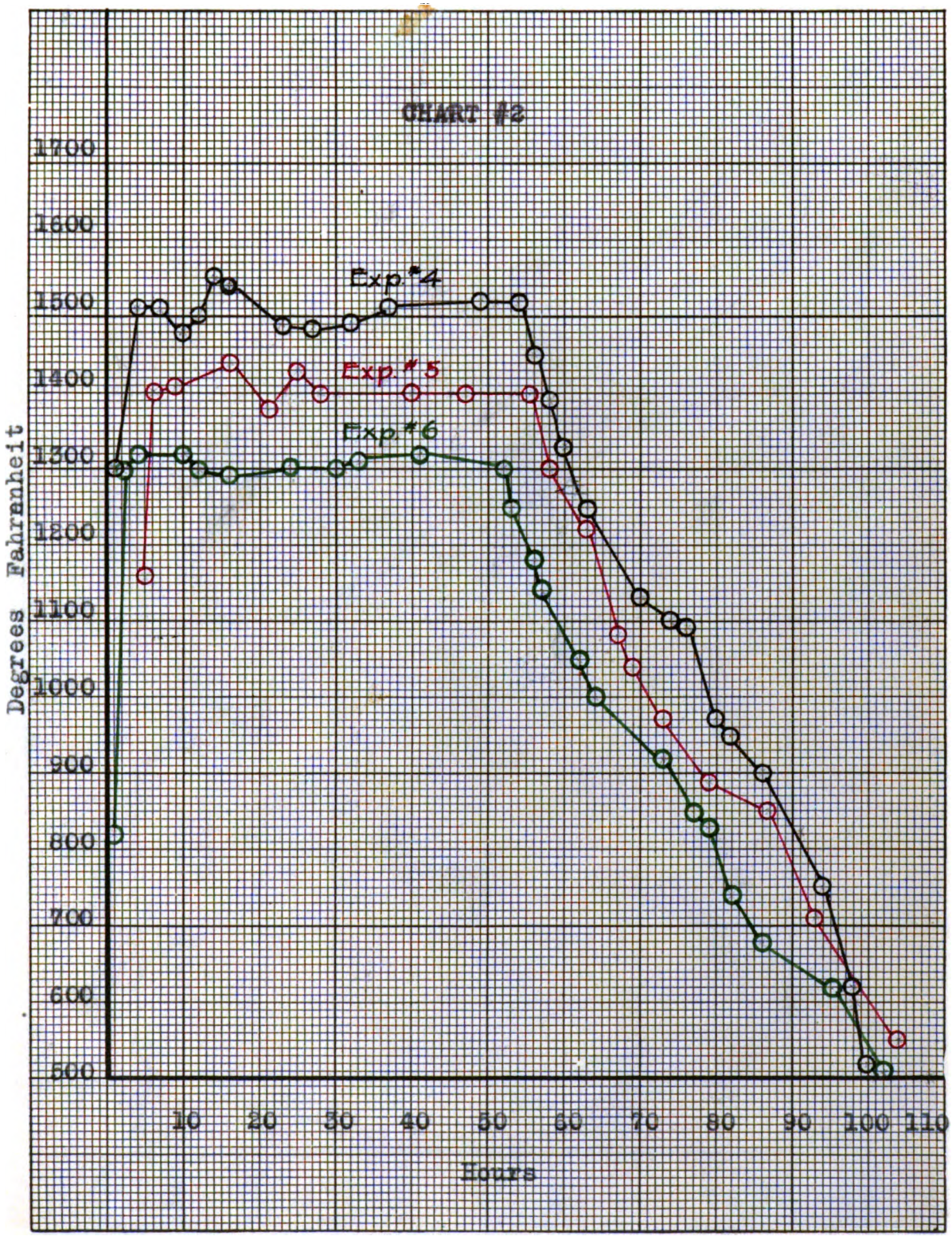

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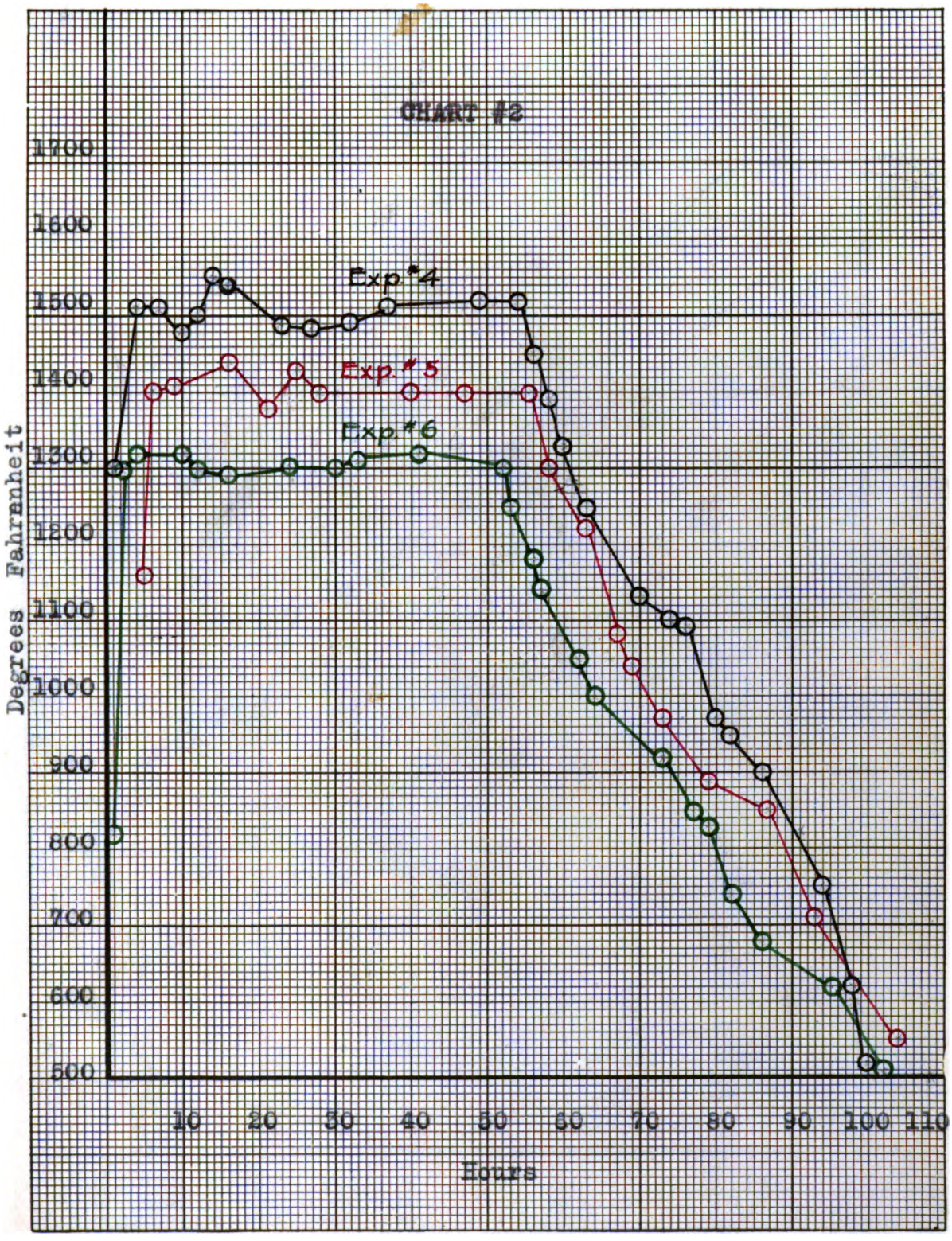

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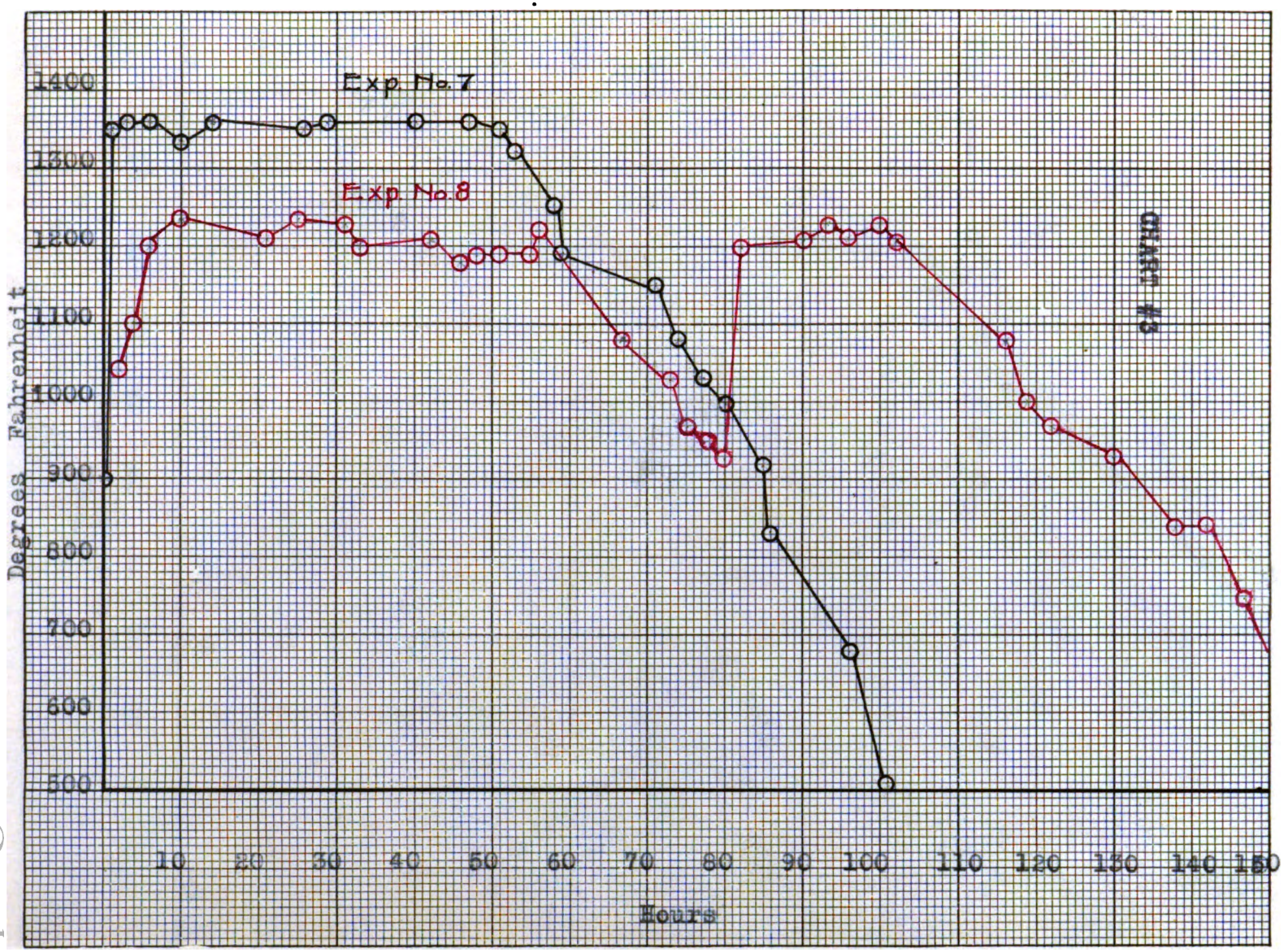

CHART #3

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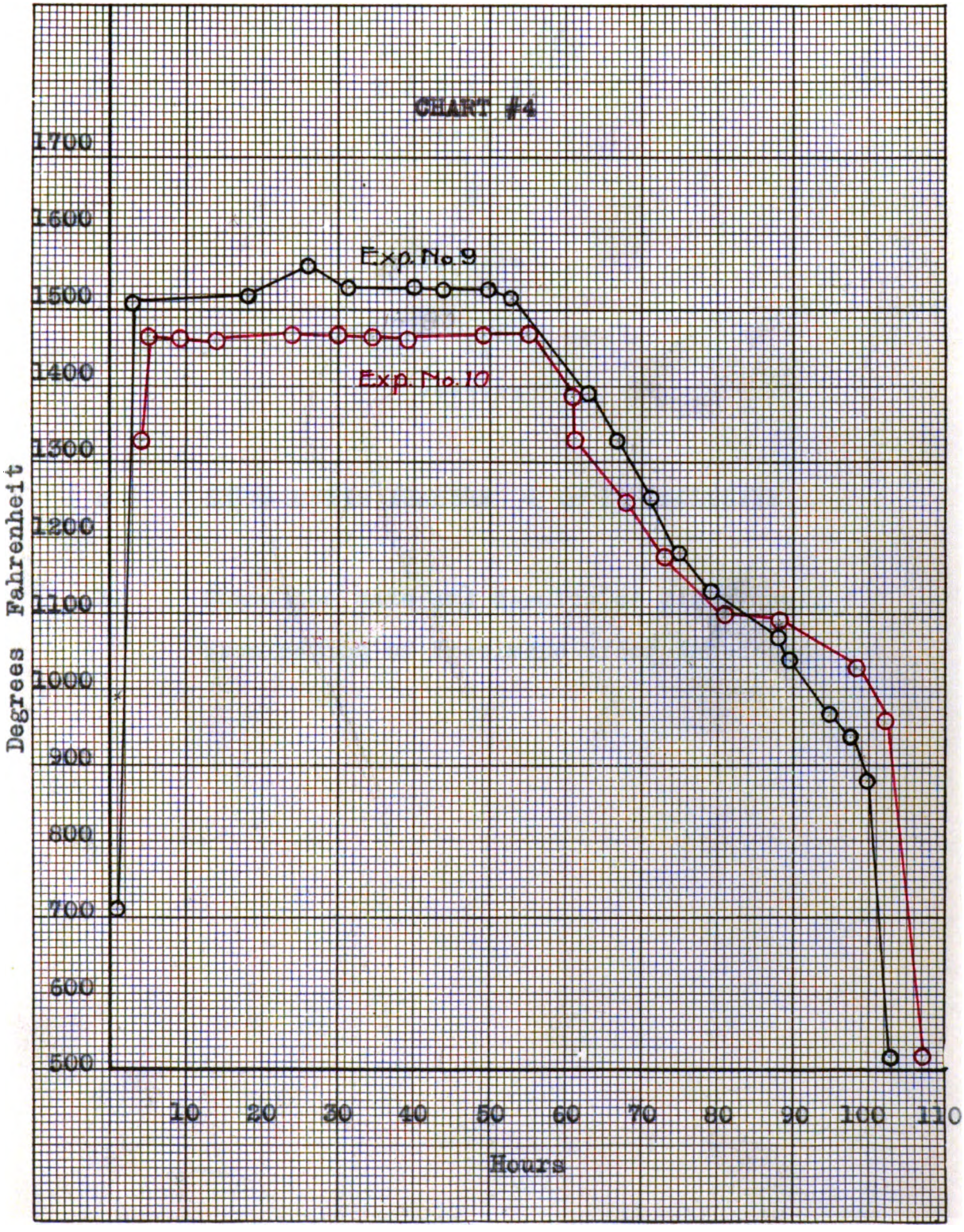

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(a) EXPERIMENTS NUMBERS 4 to 10 INCLUSIVE.

3. Summation data and Results of Microscopic Examination of Specimens after Annealing.

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ANNEALING TEMPERATURE OF 1500 degrees Fahrenheit;

TIME OF MAINTAINING SAME, 50 HOURS;

TIME OF COOLING TO 500 degrees Fahrenheit, 50 HOURS.

4 hours to 1390° F.
5 hours to 1250° F.
41 hours to 500° F.

****

ON ACCOUNT OF SPECIMENS BEING TOO HARD TO SAW, NO SECTIONS WERE MADE FOR SPECIMENS NUMBER 23, 24, 25, 26, 27 and 29, OF THIS EXPERIMENT No. 4.

Specimen #28, packed in Scale. Previously treated.

Edge	Ferrite; Temper Carbon & Pearlite.
Center	Temper Carbon and Pearlite.

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EXPERIMENT No. 5.

*****

ANNEALING TEMPERATURE OF 1400 Fahrenheit;

TIME OF MAINTAINING SAME, 50 HOURS;

TIME OF COOLING, 50 HOURS;

1 hour to 1390°F.
4 " " 1250°F.
45 " " 500°F.

****

MICROSCOPIC EXAMINATION

Specimen #30, packed in Resister Carbon.

Edge Ferrite and Pearlite.

Center Temper Carbon and Ferrite.

Specimens #31 and 32, packed in Iron Oxide & Oxide with Carbon.

Edge Ferrite

Center Ferrite and Temper Carbon.

Specimen #33, packed in Fine Fire Clay.

Edge Ferrite

Center Ferrite, Temper Carbon & Pearlite.

Specimen #34, packed in Scale.

Edge Ferrite

Center Ferrite; Pearlite & Cementite.

Specimen #35, packed in Graphite. Previously Treated.

Edge Ferrite.

Center Ferrite; Cementite and Temper Carbon.

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Specimen #36, Grey Iron. No change in structure.

Specimen #37, No packing.

Edge Ferrite.

Center Ferrite; Temper Carbon & Cementite.

****

E X P E R I M E N T No. 6

***

ANNEALING TEMPERATURE OF 1300° Fahrenheit;

TIME OF MAINTAINING SAME, 50 HOURS;

TIME OF COOLING, 50 HOURS.

1 hour to 1250° F.
49 " " 500° F.

****

MICROSCOPIC EXAMINATION

Specimen #42, packed in scale. Previously treated.

Edge Ferrite and Pearlite.

Center Only slightly changed.

ALL OF THE REST OF THE SPECIMENS WERE TOO HARD TO SAW.

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E X P E R I M E N T No. 7

*****

ANNEALING TEMPERATURE OF 1350° Fahrenheit;

TIME MAINTAINED, 50 HOURS;

TIME OF COOLING, 50 HOURS;

7 hours to 1250° F.
43 " " 500° F.

*****

ALL OF THE SPECIMENS OBTAINED IN THIS EXPERIMENT WERE EITHER TOO HARD TO CUT, OR AFTER BEING EXAMINED, SHOWED VERY LITTLE CHANGE. IN STRUCTURE FROM THE WHITE IRON.

****

E X P E R I M E N T No. 8

*****

TEMPERATURE OF ANNEALING OF 1000° to 1200° Fahrenheit;

TIME MAINTAINED, 120 HOURS;

TIME OF COOLING TO 500° F. of 36 HOURS.

****

Specimen #50, packed in Scale. Peviously treated.

Edge	Ferrite & Temper Carbon.
Center	Not entirely changed.

—

ALL OF THE REST OF THE SPECIMENS WERE TOO HARD TO SAW.

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EXPERIMENT No. 9

****

ANNEALING TEMPERATURE OF 1500° - 50° Fahrenheit;

TIME MAINTAINED, 50 HOURS;

TIME OF COOLING OF 50 HOURS,

10	hours	to	1390° F.
8	"	"	1250° F.
32	"	"	500° F.

***

MICROSCOPIC EXAMINATION

Specimen #54, packed in Graphite, SPECIAL BOX.

Edge	Pearlite.
Center	Not completely changed.

Specimen #55, packed in Fine Fire Clay, SPECIAL BOX.

Edge	Ferrite and Pearlite
Center	About half changed.

Specimen #56, packed in Graphite.

Edge	Ferrite and Pearlite.
Center	Fairly well changed.

Specimen #57, packed in Scale.

Edge	Ferrite & Pearlite.
Center	Fairly well changed.

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Specimen #58, packed in Fine Fire Clay.

Edge	Ferrite & Pearlite.
Center	Ferrite; Temper Carbon & a little Cementite.

****

E X P E R I M E N T No. 10

***

ANNEALING TEMPERATURE OF 1450°- 75° Fahrenheit;

TIME MAINTAINED, 50 HOURS;

TIME OF COOLING, 50 HOURS;

6 hours to 1390° F.
6 " " 1250° F.
38 " " 500° F.

***

ALL OF THE SPECIMENS IN THIS EXPERIMENT WERE EITHER TOO HARD TO SAW, OR SHOWED THAT THE ORIGINAL WHITE IRON STRUCTURE WAS VERY SLIGHTLY CHANGED.

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PART IV

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III. MICROGRAPHS * TEMPERATURE SERIES.

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See Figures No. 1, 2, 3, 4, 6, 7, 8, 9, 10. 12.

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IV. RESULTS AND CONCLUSIONS * TEMPERATURE SERIES.

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RESULTS AND CONCLUSIONS

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From the results obtained in this series of experiments, the conclusion is reached that for white iron of the analysis furnished, a temperature of 1400 degrees Fahrenheit is necessary to cause a complete breaking down of the Cementite into Ferrite and Temper Carbon.

Experiment #8 shows that the specimens heated for 120 hours at 1000 to 1200 degrees Fahrenheit were still unchanged; with the exception of specimen #50 which had previously been heated for a number of hours at 1600 degrees Fahrenheit, and whose interior structure was still not completely changed.

The same general results hold t rue for Experiment #6 where the annealing temperature was 1300 degrees Fahrenheit, and the period of heating was 50 hours.

The results of Experiment #5, where the annealing temperature was 1400 degrees Fahrenheit, show that only those specimens at the center of the furnace were well changed, while those near the door still had some Cementite present.

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The same general results hold true for Experiments #4 and #10, so that for the following Experiments an annealing temperature of 1550 - 1650 degrees Fahrenheit will used as the constant.

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THE EFFECTS OF DIFFERENT PERIODS OF COOLING FROM THE ANNEALING TEMPERATURE TO 500 DEGREES FAHRENHEIT, WITH VARIATIONS TO 1390 DEGREES; 1390 to 1250 DEGREES; AND 1250 TO 500 DEGREES FAHRENHEIT.

I. Constants in this series of experiments.

II. Data

Experiments #11 to 16 inclusive.

III. Micrographs.

IV. Results and Conclusions.

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PART IV

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I. CONSTANTS * COOLING SERIES.

1. Packing materials.

2. Temperature = 1550 - 1650° F.

3. Time of annealing = 50 hours.

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II. DATA * COOLING SERIES.

(a) Experiments #11 to 16 inclusive.

1. Data showing kind of packing used; number of specimen; and conditions of packing materials and specimens after annealing.
2. Time - Temperature heating and cooling curves. Charts #5 to 10 inclusive.
3. Summation data and results of microscopic examination of specimens after annealing.

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(A) EXPERIMENTS NUMBERS 11 to 16 INCLUSIVE.

1. Data showing the kind of packing used; number of the specimen; and conditions of the packing materials and specimens after annealing; upon unpacking.

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EXPERIMENT No. 11

Specimen #66, packed Graphite. Packing burned to ash at ends where a fairly heavy scale was formed.

Specimen #67, packed in Scale. Heavy scale; packing adherent and caked.

Specimen #68, packed in Fine Fire Clay. Fairly heavy and tenacious scale; packing adherent.

Specimen #69, packed in Scale containing 25% of Graphite by volume. Heavy scale; adherent packing.

Specimen #70, packed in Chromite. Very heavy scale; adherent packing.

Specimen #71, No packing. Heavy scale.

Specimen #72, packed in Fine Fire Clay containing 25% of Graphite by volume. Heavy scale; adherent packing.

****

EXPERIMENT No. 12

Specimen #73, packed in Scale. Fairly heavy and tenacious scale; adherent packing.

Specimen #74, packed in Scale containing 25% of Graphite, in SPECIAL BOX. No scale; specimen clean.

Specimen #75, packed in Chromite. Fairly heavy scale; adherent packing.

Specimen #76, packed in Fine Fire Clay. Heavy scale; adherent packing.

Specimen #77, packed in Graphite. Packing burned and adherent; fairly heavy scale.

Specimen #78, packed in Iron Oxide. Fairly heavy, tenacious scale; adherent packing.

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Specimen #79, No packing. Heavy scale.

Specimen #80, packed in Sand containing 35% of Graphite by volume. Heavy, tenacious scale; packing adherent.

****

EXPERIMENT No. 13

Specimen #81, packed in Scale in SPECIAL BOX. Thin scale; packing not caked.

Specimen #82, packed in Graphite in SPECIAL BOX. No scale.

Specimen #83, packed in Scale. Heavy and tenacious scale with packing adherent.

Specimen #84, packed in Graphite. Heavy scale; packing burned.

Specimen #85, packed in a mixture of fire clay and neat cement. Packing disintegrated and not adherent.

Specimen #86, packed in Chromite. Heavy scale; adherent packing.

Specimen #87, No packing. Heavy scale.

****

EXPERIMENT No. 14

Specimen #88, packed in Scale in SPECIAL BOX. Thin scale; packing caked.

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Specimen #89, packed in Scale. Heavy and tenacious scale; with packing adherent.

Specimen #90, packed in Fine Fire Clay. Heavy scale easy to remove; packing somewhat adherent.

Specimen #91, packed in Graphite, Heavy and tenacious scale; packing burned.

Specimen #92, No packing. Heavy scale.

****

EXPERIMENT No. 15

Specimen #93, packed in Bone Black in SPECIAL BOX. No scale; packing not burned.

Specimen #94, packed in Scale in SPECIAL BOX. No scale; packing caked.

Specimen #95, packed in Fine Fire Clay. Fairly heavy scale; adherent packing.

Specimen #96, packed in Scale. Fairly heavy & tenacious scale; adherent packing.

Specimen #97, No packing. Heavy and tenacious scale.

Specimen #98, packed in Chromite containing 25% of Bone Black.
Fairly heavy & tenacious scale; packing adherent.

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EXPERIMENT No. 16

Specimen #99, packed in Bone Black in SPECIAL BOX. No scale; packing somewhat burned at one end.

Specimen #100, packed in Fine Fire Clay in SPECIAL BOX. No scale.

Specimen #101, packed in Fine Fire Clay. Heavy scale; packing adherent.

Specimen #102, packed in Scale. Heavy and tenacious scale; packing adherent.

Specimen #103, packed in Scale In SPECIAL BOX. Specimen clean; packing grey in color.

Specimen #104, No packing. Heavy scale.

Specimen #105, packed in Iron Oxide containing 35% of Bone Black. Fairly heavy and tenacious scale.

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(a) EXPERIMENTS NUMBERS 11 to 16 INCLUSIVE.

3. Time - Temperature Heating and Cooling Curves.

Charts #5 to 10 inclusive.

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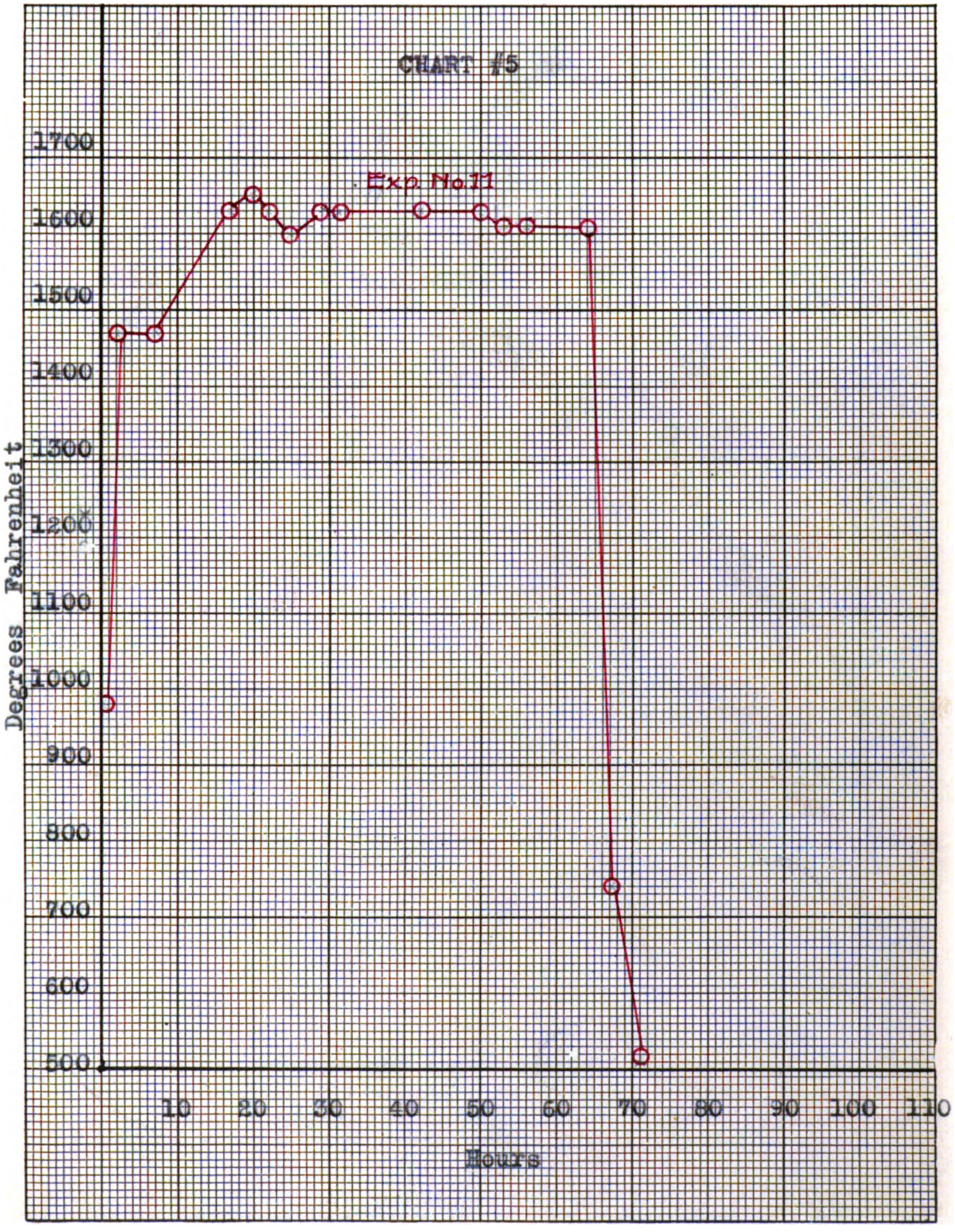

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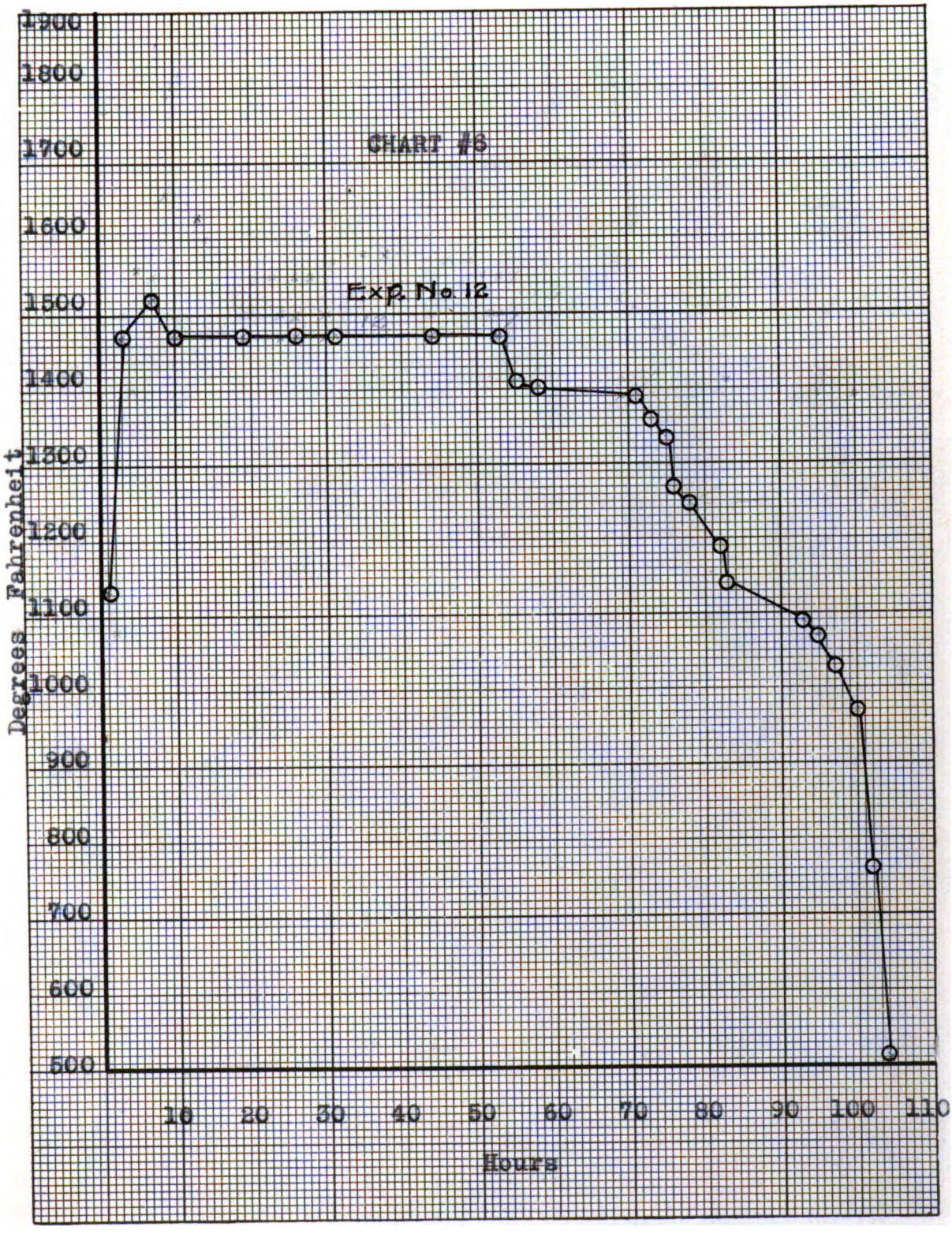

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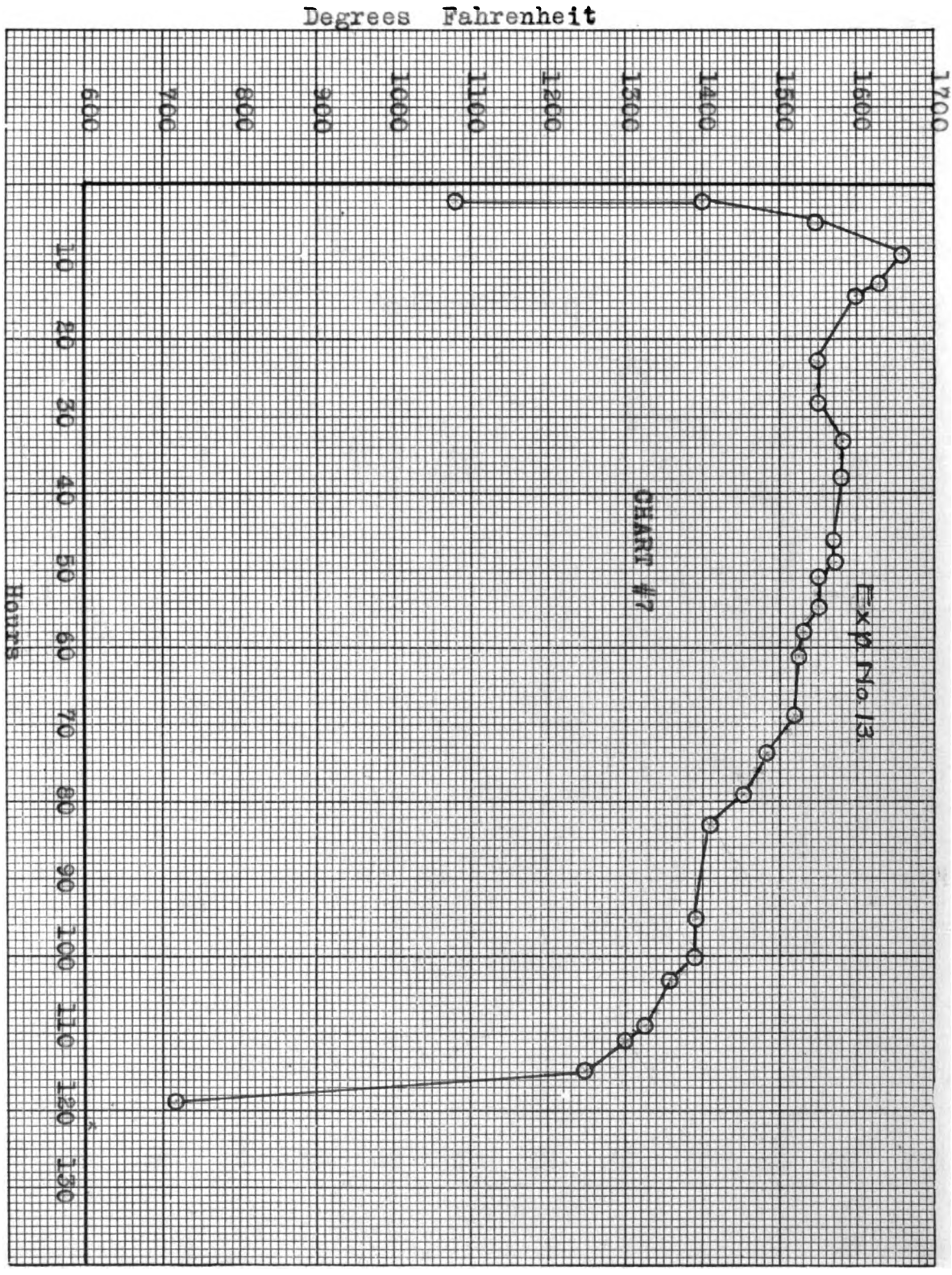

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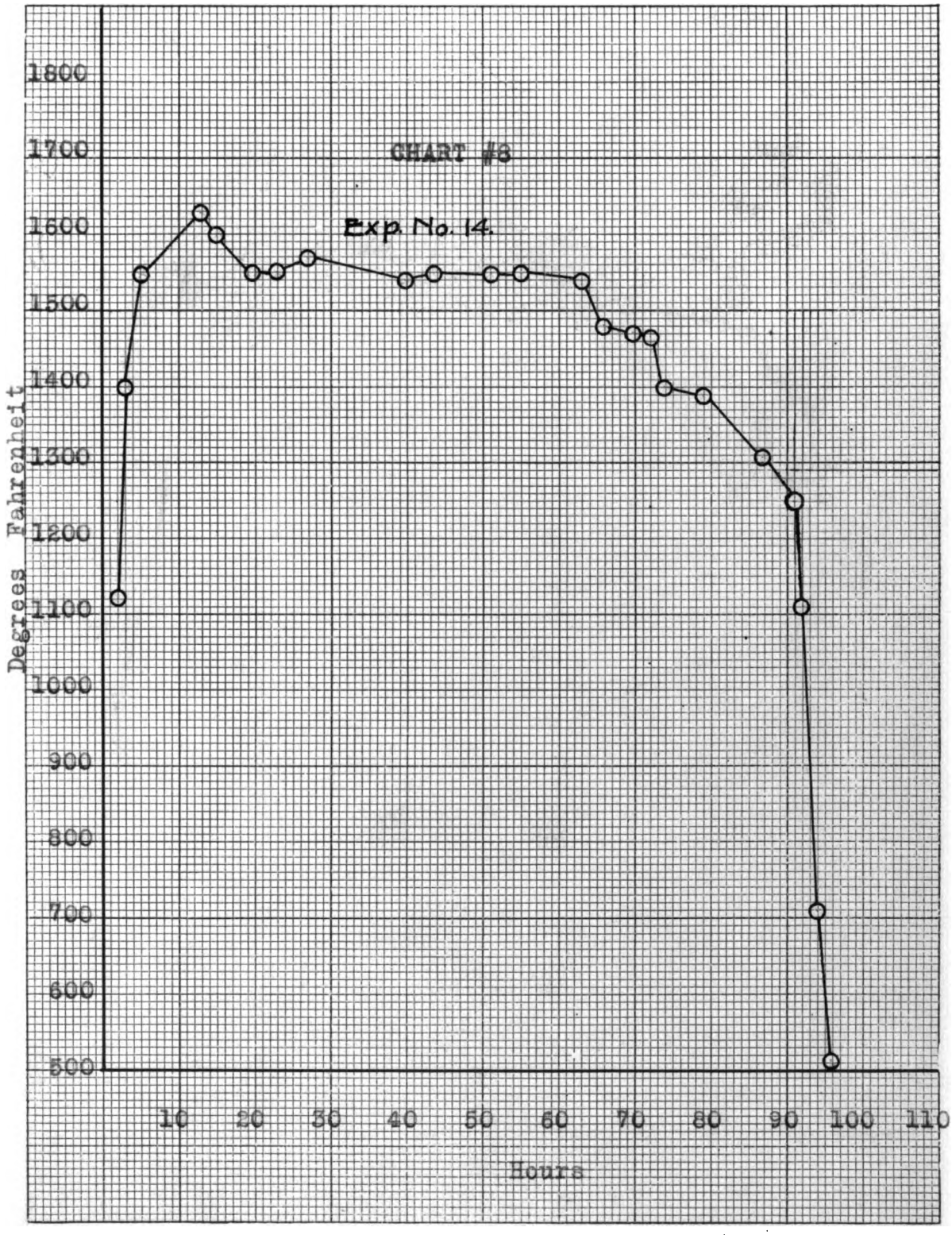

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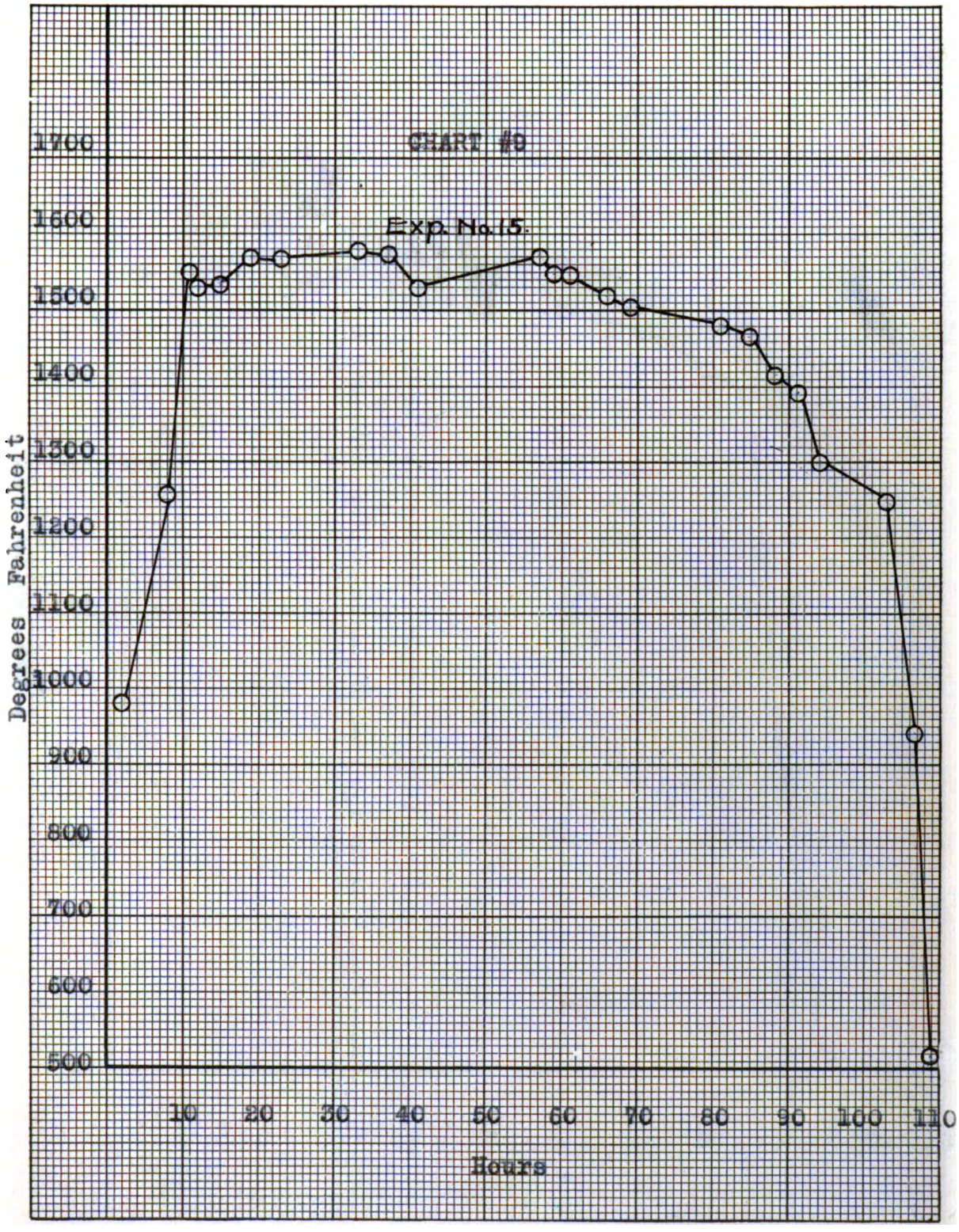

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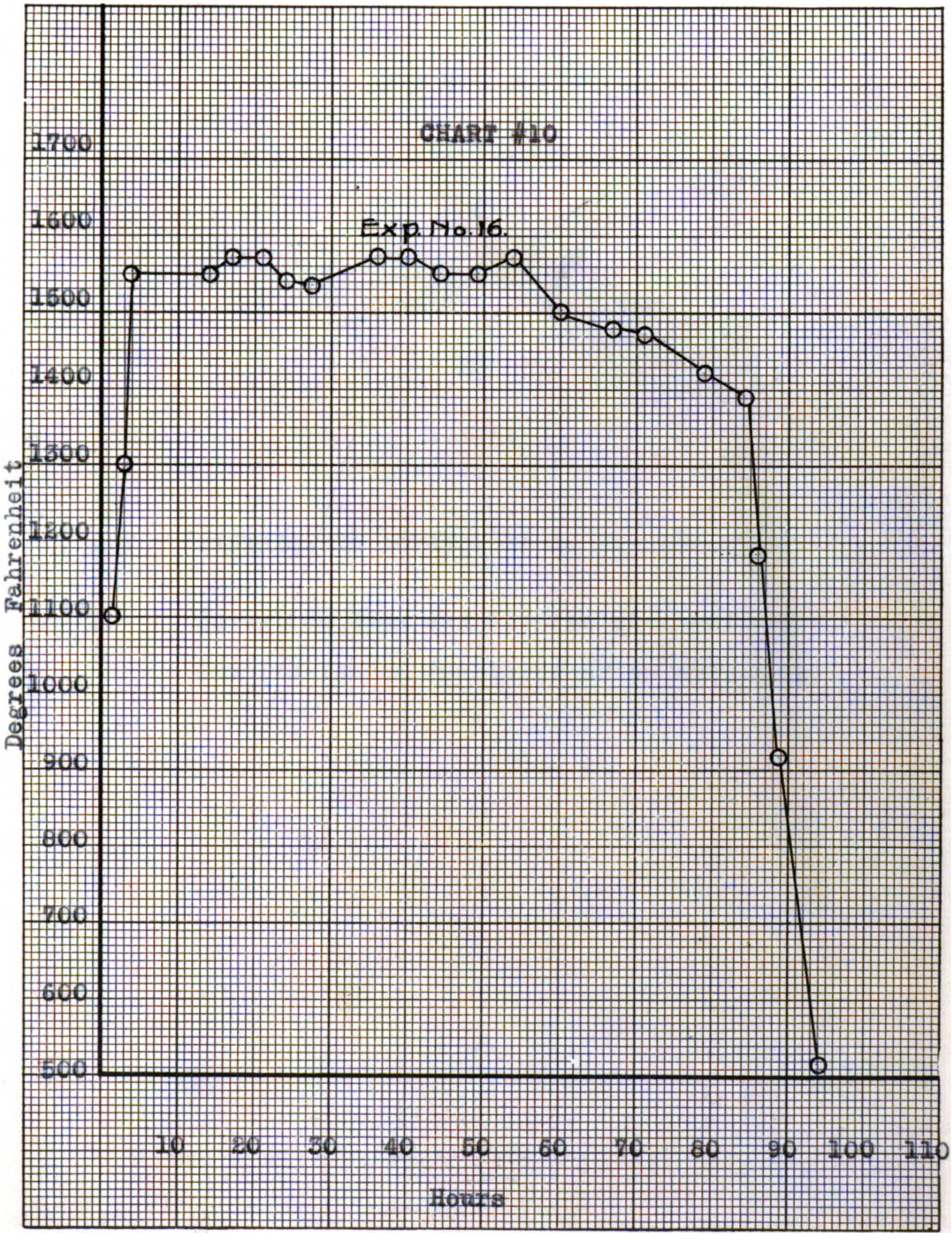

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(a) EXPERIMENTS NUMBERS 11 to 16 INCLUSIVE.

3. Summation data and Results of Microscopic Examination of Specimens after Annealing.

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EXPERIMENT No. 11

ANNEALING TEMPERATURE OF 1600 degrees Fahrenheit;

TIME MAINTAINED, 39 HOURS,

TIME OF COOLING TO 500° Fahrenheit, 14 HOURS.

*****

NOTE:- Furnace burned out allowing a very rapid cooling to take place.

****

Specimen #66, packed in Graphite.

Edge	Ferrite & Pearlite.
Center	PURE PEARLITE.

THE REST OF THE SPECIMENS IN THIS EXPERIMENT SHOWED,-

Edge	Ferrite and Pearlite.
Center	High Carbon Steel.

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EXPERIMENT No. 12

ANNEALING TEMPERATURE OF 1450-1500° Fahrenheit ;

TIME MAINTAINED, 50 HOURS;

TIME OF COOLING OF 50 HOURS,

18 hours to 1390° F.
7 " " 1250° F.
25 " " 500° F.

*****

Specimens #76 & 77 which were in the center of the furnace, showed a fairly good structure. The rest of the specimens showed an edge of Ferrite, with the interior not completly changed.

****

EXPERIMENT No. 13

ANNEALING TEMPERATURE, 1550 - 1600 degrees Fahrenheit;

TIME MAINTAINED, 50 HOURS;

TIME OF COOLING OF 70 HOURS;

45 hours to 1390° F.
15 " " 1250° F.
10 " " 500° F.

*****

All of the specimens in this experiment showed a good structure, both edge and center.

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EXPERIMENT No. 14

ANNEALING TEMPERATURE OF 1550 degrees Fahrenheit;

TIME MAINTAINED OF 50 HOURS;

TIME OF COOLING OF 40 HOURS;

24 hours to 1390° F.
12 " " 1350° F.
4 " " 500° F.

****

All of the specimens in this experiment showed the same general structure, as follows,-

Edge Ferrite and Pearlite.

Center Temper Carbon, Ferrite & Pearlite.

****

EXPERIMENT No. 15

ANNEALING TEMPERATURE OF 1550 degrees Fahrenheit;

TIME MAINTAINED OF 50 HOURS;

TIME OF COOLING OF 48 HOURS,

30 hours to 1390° F.
12 " " 1350° F.
6 " " 500° F.

***

All of the specimens in this experiment showed;

Edge Ferrite.

Center Ferrite and Temper Carbon.

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EXPERIMENT No. 16

ANNEALING TEMPERATURE OF 1550 degrees Fahrenheit;

TIME MAINTAINED OF 50 HOURS;

TIME OF COOLING OF 40 HOURS.

30	hours	to	1390° F.
1	"	"	1250° F.
9	"	"	500° F.

***

Specimen #99, packed in Bone Black in SPECIAL BOX.

Edge	Almost pure Carbide, and Pearlite.
Center	Pearlite.

The rest of the specimens showed the same general structure as follows,-

Edge	Ferrite and Pearlite.
Center	Temper Carbon; Ferrite & Pearlite.

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P A R T IV

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III. M I C R O G R A P H S * COOLING SERIES.

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See Figures 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12.

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PART IV

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C

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IV. RESULTS AND CONCLUSIONS * TEMPERATURE SERIES.

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It was early noticed that the rate of cooling had an important effect upon the malleablizing process. By referring to the first series of experiments, it will be seen that experiment #1 gave the best results. In t his experiment, the time of cooling to 1400° Fahrenheit and 1250° Fahrenheit was much longer than for #2 and #3. In experiments #2 and #3, the interior structure was found to be composed of Ferrite, Temper Carbon and Pearlite, showing that rapid cooling tends to form a steely structure. This fact is also shown in experiment #11 where the furnace failed and the charge cooled very rapidly; the resulting interior structure was a high carbon steel.

Experiment #12 shows that a good malleable structure was obtained only for those specimens at the center of the furnace. Experiment #15 shows that a good structure was obtained for all specimens. In this experiment, the time of cooling was as follows,- 30 hours to 1390° F; 12 hours from 1390° to 1250° F.; and 6 hours from 1250° to 500° F.; making a total of 48 hours. In both of these experiments the total time of cooling was practically the same, but t he time of cooling from the annealing temperature

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to 1250° Fahrenheit was much longer for #15 than for #12. This fact tends to show that the rate of cooling should be slow down to about 1250° degrees Fahrenheit, after which it may become rapid without endangering the malleable structure.

As the result of this series of experiments, the time of cooling will be taken as 48 hours, divided about as follows,- 30 hours to 1390° F.; 10 to 12 hours from 1390° to 1250° F.; and 6 to 8 hours from 1250° to 500° degrees Fahrenheit. The point 1250° degrees Fahrenheit was taken because it is about 25 degrees below the A r_1 Point on the Roozeboom Diagram. This point is the critical temperature at which the solid solution of iron carbide breaks down into it's constituents of Ferrite and Cementite, and is known as Pearlite.

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THE EFFECTS OF DIFFERENT PERIODS OF ANNEALING.

I. Constants in this series of experiments.

II. Data,

Experiments #17 t o #23 Inclusive.

III. Micrographs.

IV. Results and Conclusions.

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D

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I. CONSTANTS * ANNEALING PERIOD SERIES.

1. Packing materials.
2. Temperature of Annealing 1500 - 1650° F.
3. Time of Cooling. (See C)

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II. D A T A

(a) Experiments #17 to #23 inclusive.

1. Data showing kind of packing used; numbers of specimens; etc., etc.

2. Time & Temperature heating and cooling curves. Charts #11 t o #17 inclusive.

3. Summation data and results of microscopic examination of specimens after annealing.

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II

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(a) EXPERIMENTS #1 7 to 33 INCLUSIVE.

1. Data showing the kind of packing materials used; number of the specimens; and conditions of the packing and specimens upon unpacking after the annealing process.

******

NOTE:- No change in this data over that given under B and C., t o which please refer.

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EXPERIMENT No. 17

Specimen #106, packed in Bone Black in Special Box.

Specimen #107, packed in Scale in Special Box.

Specimen #108, packed in Fine Fire Clay.

Specimen #109, packed in Scale.

Specimen #110, No packing.

EXPERIMENT No. 18

Specimen #111, packed in Scale.

Specimen #112, packed in Fine Fire Clay.

Specimen #113, packed in Scale in Special Box.

Specimen #114, packed in Bone Black containing $BaCO_3$ (Spec'l)

Specimen #115, No packing.

Specimen #116, packed in Bone Black.

EXPERIMENT No. 19

Specimen #117, packed in Scale.

" #118, " " Fine Fire Clay.

" #119, packed in Bone Black containing $BaCO_3$, in Special Box.

" #120, packed in Bone Black.

" #121, packed in Cupric Oxide. Oxide was all reduced to metallic copper.

" #122, No Packing.

" #122a, packed in a mixture of Bone Black, Chromite and Barium Carbonate.

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EXPERIMENT No. 20

Specimen #123, packed in Bone Black containing Barium Carbonate, in Special Box.

" #124, packed in Fine Fire Clay, Special.

" #125, packed in Scale.

" #126, packed in Fine Fire Clay.

" #127, No packing.

EXPERIMENT No. 21

Specimen #128, packed in Cupric Oxide.

Specimen #129, packed in Fine Fire Clay.

" #130, packed in Scale.

" #131, No Packing.

EXPERIMENT No. 22

Specimen #132, packed in Fine Fire Clay.

Specimen #133, packed in Scale.

Specimen #134, No Packing.

EXPERIMEENT No. 23

Specimen #135, packed Scale.

Specimen #136, packed in Fine Fire Clay.

Specimen #137, packed in Cupric Oxide in ordinary manner; the oxide was not reduced to metallic copper.

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II

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(a) EXPERIMENTS #17 to 23 INCLUSIVE.

2. Time - Temperature Heating and Cooling Curves.

Charts #11 to #17 inclusive.

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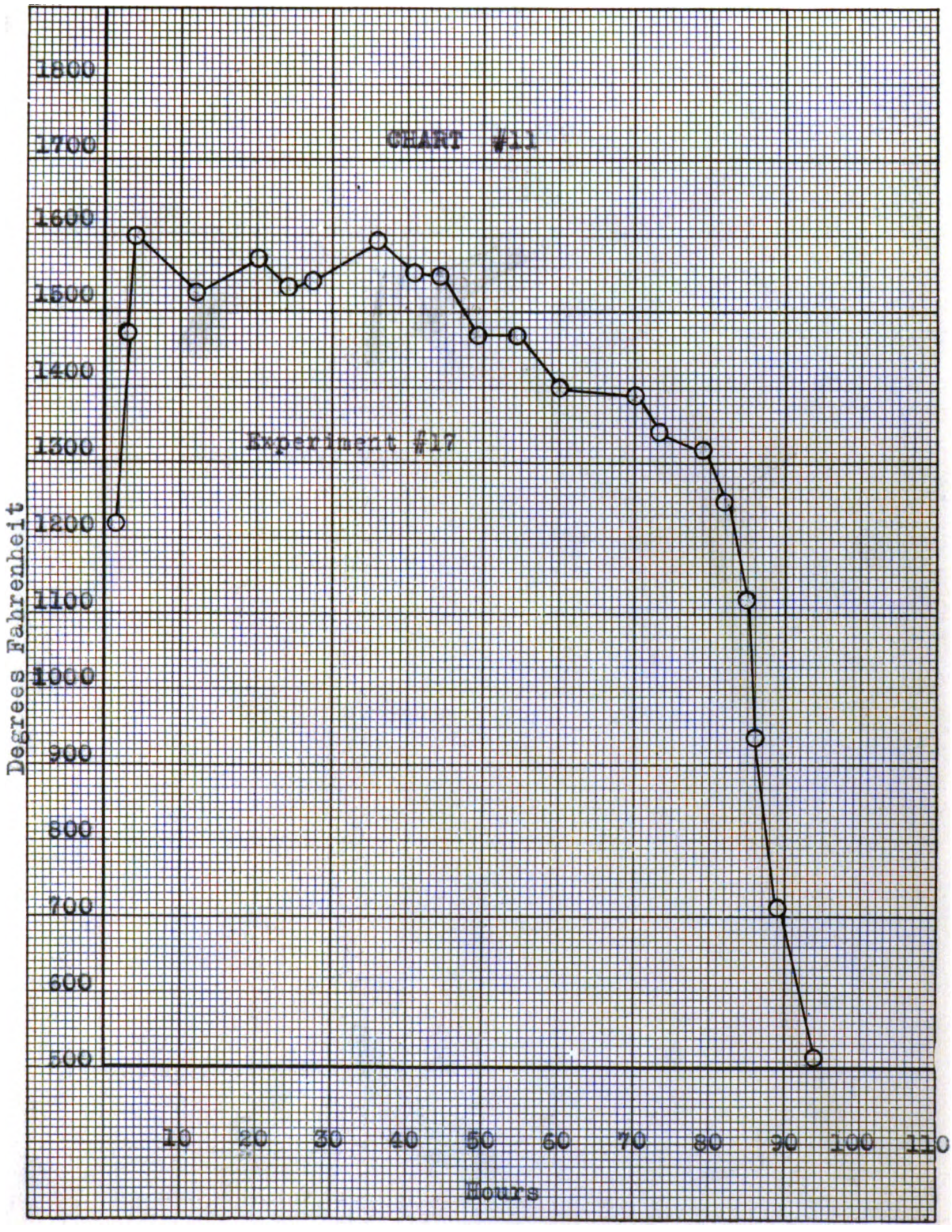

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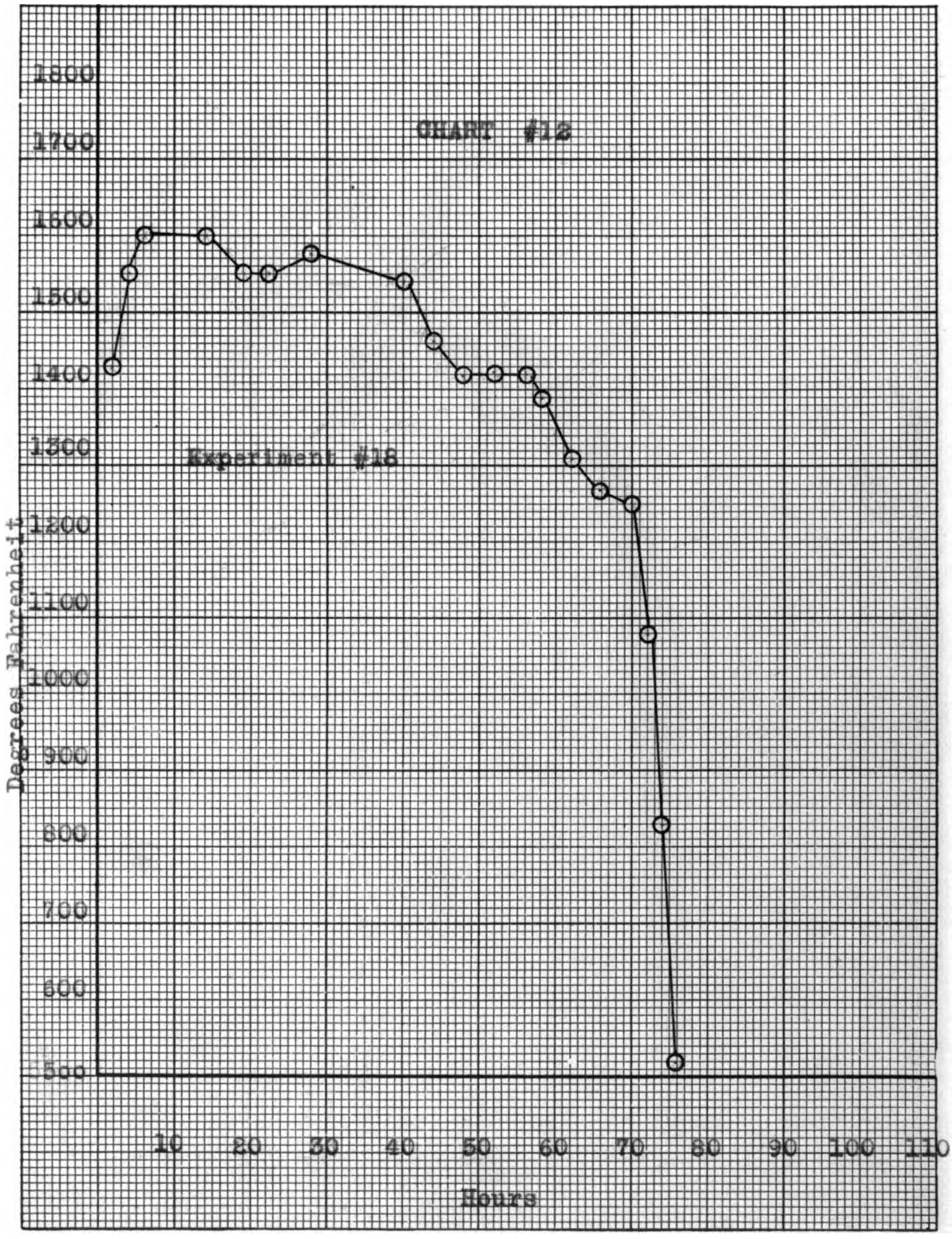

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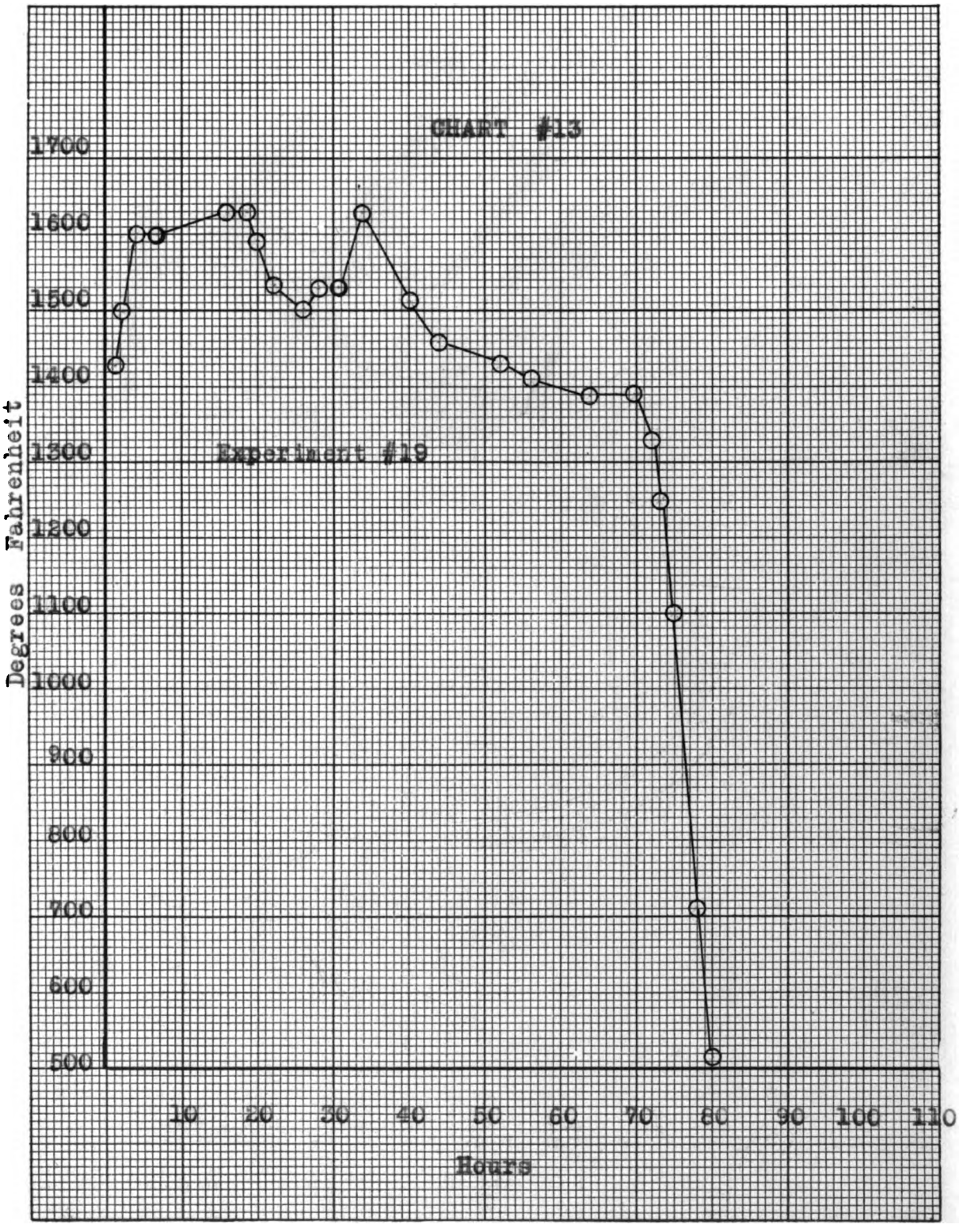

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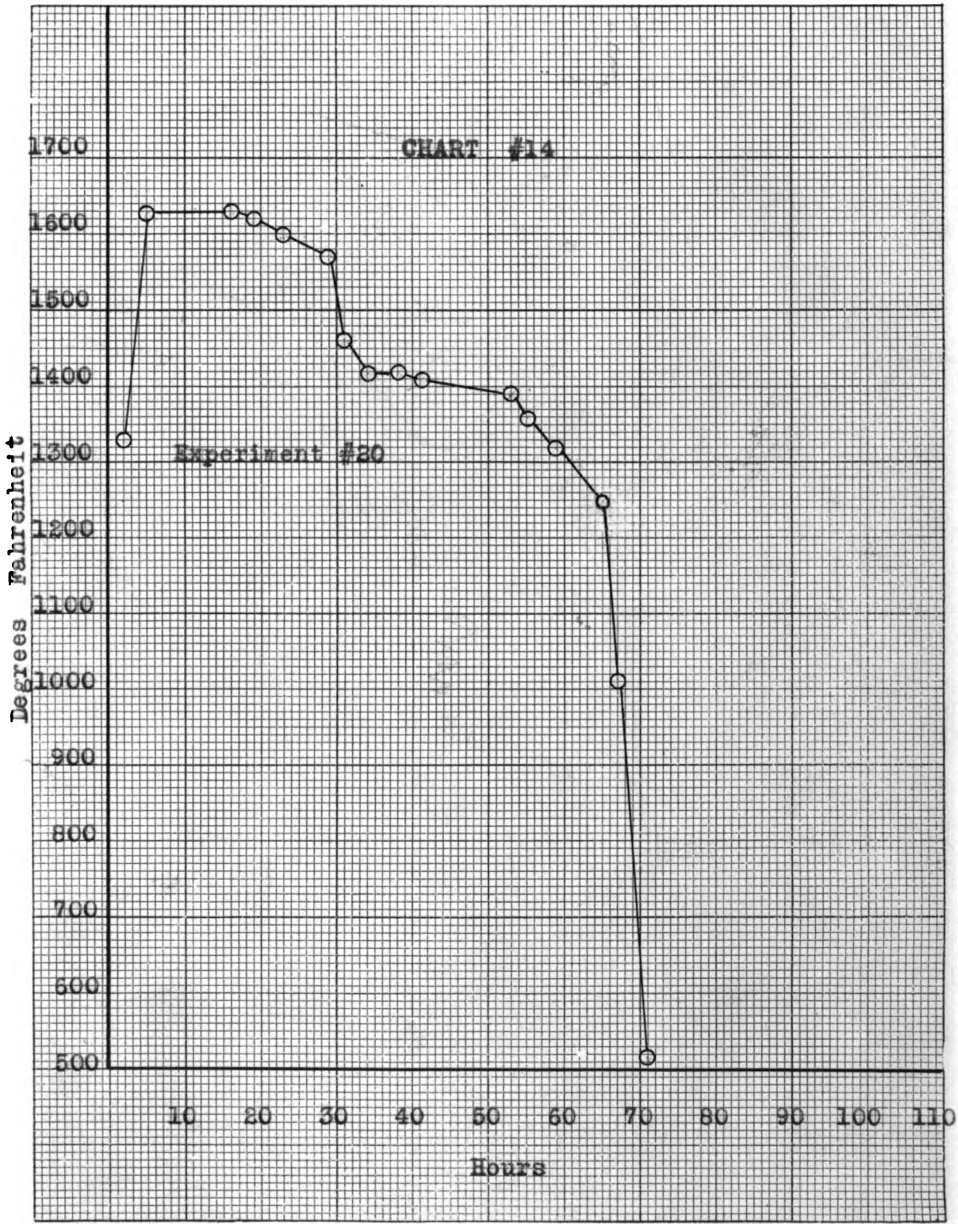

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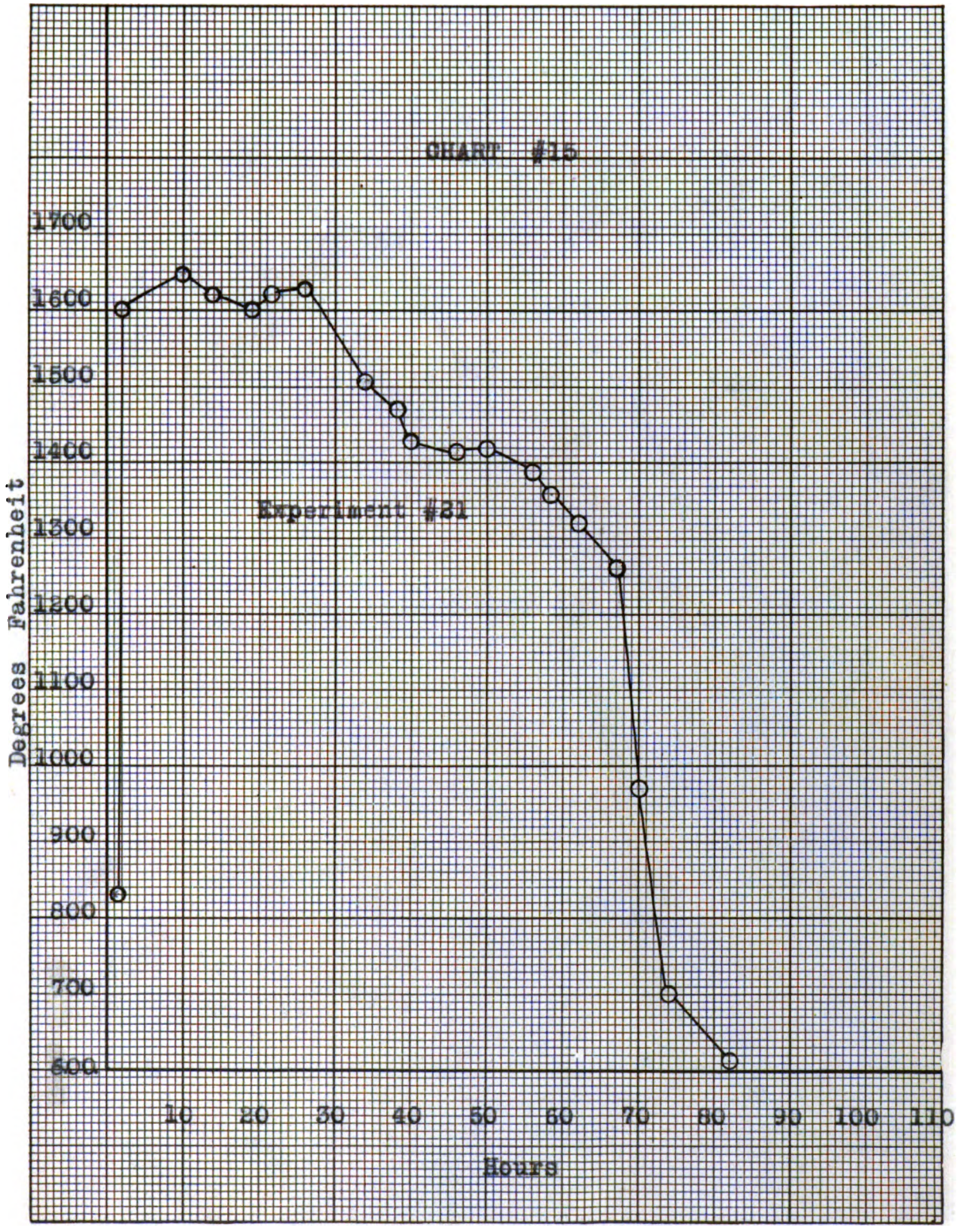

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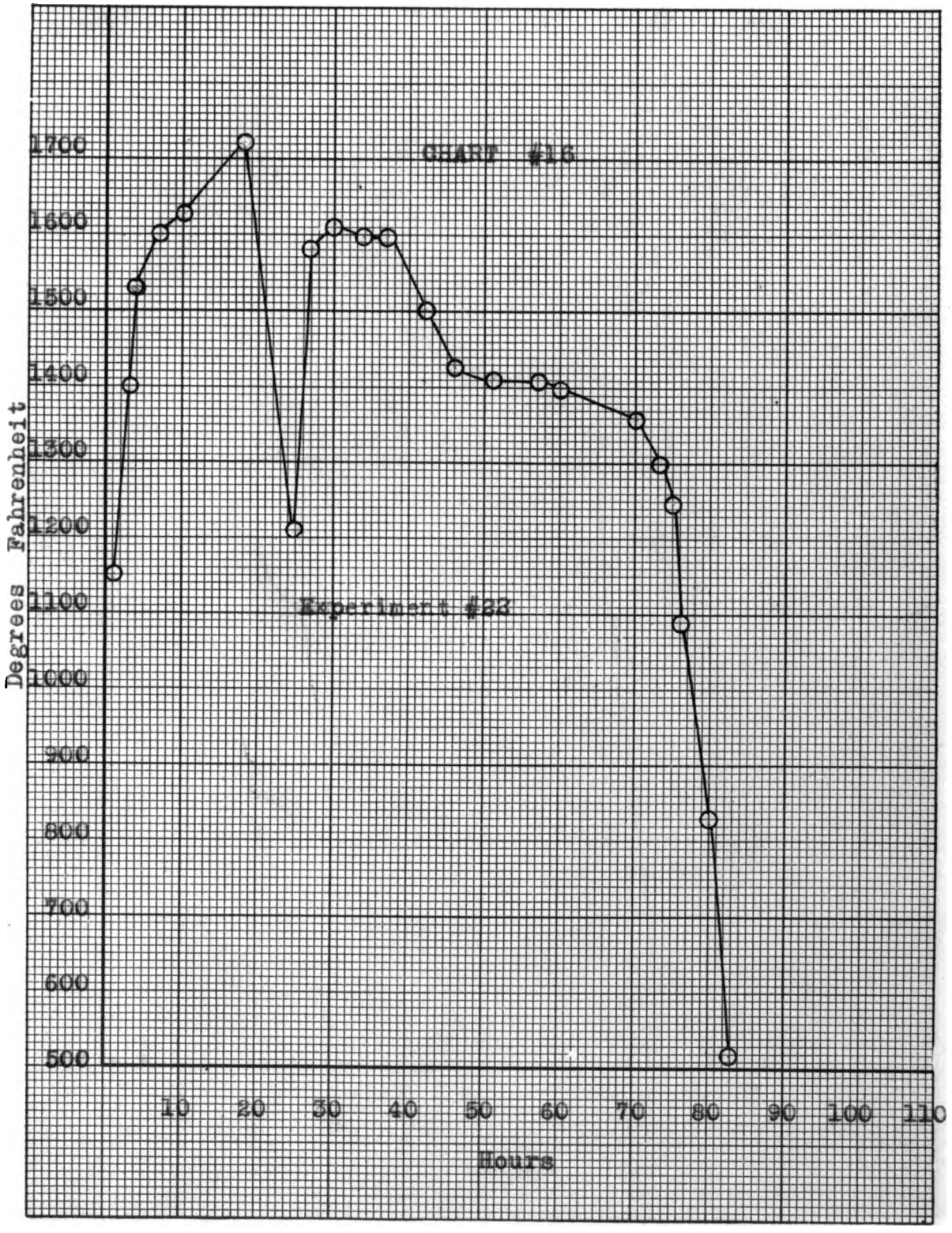

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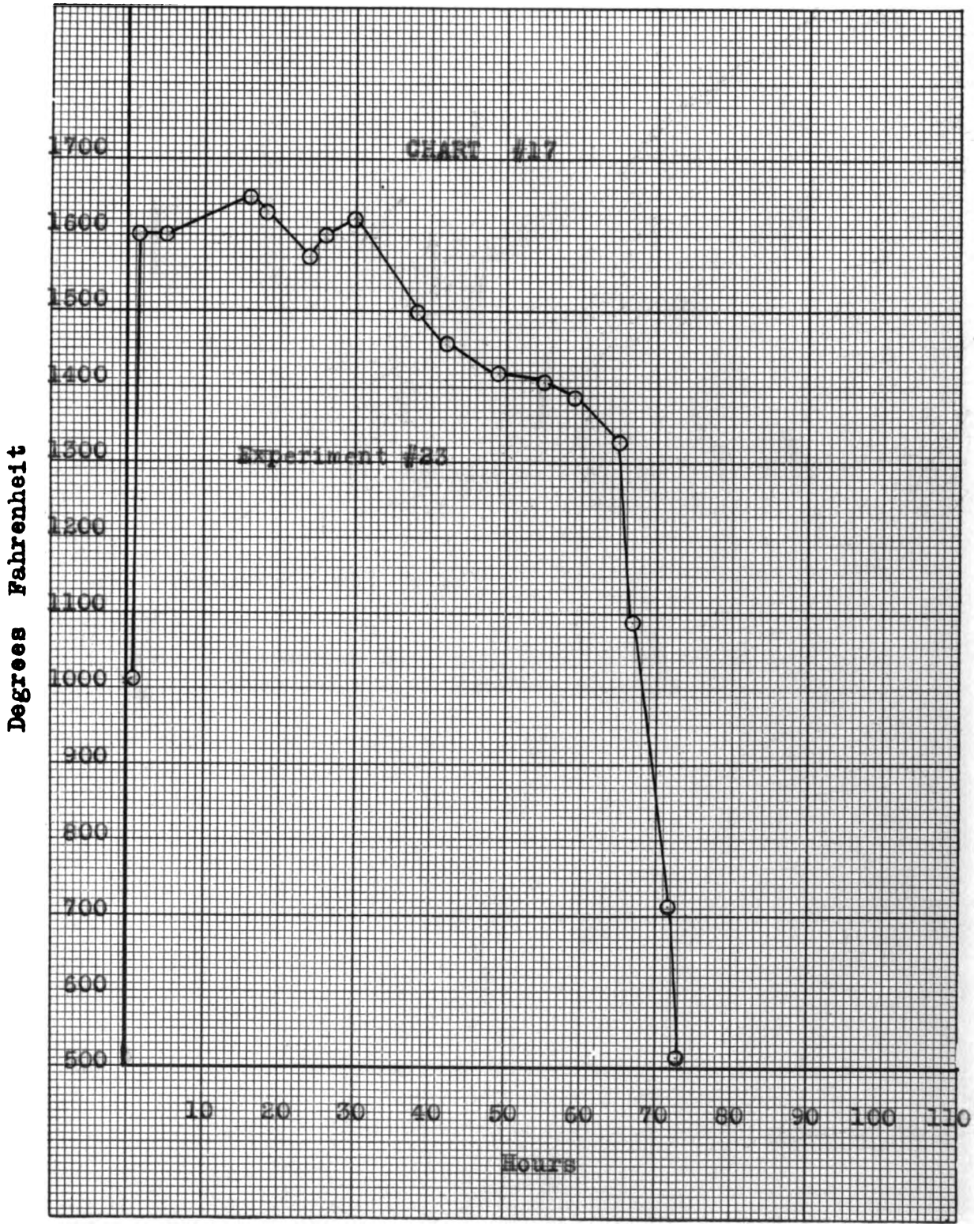

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(a) EXPERIMENTS #17 to #23 INCLUSIVE.

3. Summation Data and Results of Microscopic Examination of Specimens after Annealing.

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EXPERIMENT No. 17

ANNEALING TEMPERATURE OF 1500-1600 degrees Fahrenheit;

TIME OF COOLING TO 1250° Fahrenheit,-

23 hours to 1390° F.
12 " " 1250° F.

TIME OF HEATING, 43 HOURS.

****

Specimen #106, packed in Bone Black in Special Box.

Edge Very High Carbon Steel (Good Eutectoid)

Center Temper Carbon, Ferrite & Pearlite.

****

The rest of the specimens were as follows,-

Edge Ferrite

Center Temper Carbon, Ferrite & Pearlite.

****

EXPERIMENT No. 18

ANNEALING TEMPERATURE, 1550 - 1600 F.;

TIME OF COOLING TO 1250,- 30 HOURS.

TIME OF HEATING,- 36 HOURS.

****

Specimen #114, packed in Bone Black & Barium Carbonate.

Edge CEMENTITE

Center Ferrite; Temper Carbon & a litt le carbide.

Note: The rest of the specimens had an edge of Ferrite, and an interior of Ferrite, Temper Carbon & a little Carbide.

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EXPERIMENT No. 19

ANNEALING TEMPERATURE OF 1500 - 1600 Fahrenheit;

TIME OF HEATING OF 38 HOURS;

TIME OF COOLING TO 1250 Fahrenheit,

30 hours to 1390 F.
3 " " 1250 F.

****

All of the specimens in this experiment had a rim of either Ferrite or a mixture of Ferrite and Pearlite; t he interior structure was composed of Temper Carbon, Ferrite and Cementite.

****

EXPERIMENT No. 20

ANNEALING TEMPERATURE OF 1600 degrees Fahrenheit;

TIME OF HEATING OF 18 HOURS;

TIME OF COOLING TO 1250 Fahrenheit,

30 hours to 1390 F.
12 " " 1250 F.

***

All of the specimens in this experiment showed the following structure,-

Edge	Pearlitic
Center	Pearlite and Cementite.

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EXPERIMENT No. 21

ANNEALING TEMPERATURE OF 1600 degrees Fahrenheit;

TIME MAINTAINED OF 24 HOURS;

TIME OF COOLING TO 1250 degrees Fahrenheit,

30 hours to 1390 F.
12 " " 1250 F.

***

All specimens had t he following structure,-

Edge	Ferrite and Pearlite.
Center	Ferrite, Cementite & Pearlite.

****

EXPERIMENT No. 22

ANNEALING TEMPERATURE OF 1600 degrees Fahrenheit;

TIME MAINTAINED OF 30 HOURS;

TIME OF COOLING TO 1250 degrees Fahrenheit,

30 hours to 1390 F.
10 " " 1250 F.

All the specimens had a good structure as follows,-

Edge	Ferrite
Center	Temper Carbon and Ferrite.

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EXPERIMENT No. 23

ANNEALING TEMPERATURE OF 1600 degrees Fahrenheit;

TIME MAINTAINED OF 30 HOURS;

TIME OF COOLING TO 1250 degrees Fahrenheit,

36 hours to 1390 F.
9 " " 1250 F.

***

All of the specimens in this experiment had a structure as follows,-

Edge	Thin layer of Ferrite & Bearlite.
Center	Temper Carbon, Ferrite & Cementite.

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PART IV

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III. MICROGRAPHS

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See Figures 1, 2, 3, 4, 5, 6,
8, 9, 10, 12.

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IV. RESULTS AND CONCLUSIONS.

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RESULTS AND CONCLUSIONS

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This series of experiments shows that a malleable structure may be obtained in 36 hours, using a temperature of 1500 to 1650 degrees Fahrenheit; although 42 hours would be a safer period to use.

It is evident that a high temperature cuts down the time of heating as shown in experiment #32; and an experiment conducted outside of this series showed that it was possible to get a malleable structure in 18 hours when an annealing temperature of 1800 degrees Fahrenheit was used.

The conclusion reached is that a temperature of 1550° t o 1650 degrees Fahrenheit is t he best temperature to use inasmuch as it is neither too low or too high to endanger malleablization.

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PART V.

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PART V

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AN EXPERIMENT SHOWING WHAT BECOMES OF THE CARBON AT THE SURFACE OF WHITE CAST IRON, DURING THE PROCESS OF PRODUCING MALLEABLE IRON.

****

I. Introduction.

II. Apparatus and Methods.

III. Data.

IV. Results and Conclusions.

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INTRODUCTION

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The question of the disappearance of the carbon, or the decarbonization of the rim (skin effect) of malleable iron, has been a much discussed one. It is held by some that the carbon migrates to the interior and remains in the casting, while others claim that the carbon migrates out and disappears entire from the casting. It is obvious that if the carbon migrates out and leaves the iron at the temperature used for annealing, it must do so in the form of a carbonaceous gas. Hence, an analysis of the gases evolved by the iron during the malleablizing process, using no packing material, would report their exact composition and reveal the presence or absence of carbonaceous gases. From data of this kind, the method of decarbonization could be more definitely shown.

In this connection, the following preliminary experiment was performed. A piece of white iron was annealed in Cupric Oxide, the idea being to detect the presence of CO by noticing the degree of reduction of the oxide. The result of this experiment showed an extended and complete reduction of the oxide to metallic copper, but inasmuch as some reduction of the

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cupric oxide would occur anyway, due to the higher heat of formation of the oxide of iron over that of copper, no definite conclusions could be drawn from the result of this experiment.

The final proof of the presence of a carbonaceous gas was therefore made by collecting the gas coming off from the specimen during the annealing period, and analizing it according to the Hempel Analysis.

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APPARATUS AND METHODS

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APPARATUS

1. A piece of white iron 1 inch square and 6 inches long, weighing 700 grams; used as the specimen.

2. A closed container to hold above consisting of an 1 1/2" X 5" nipple, with an iron cap for one end, and reduced to a 1/4" pipe at the other.

3. 1/4 inch pipe and connections for leading gas from container to sampling tubes.

4. Glass gas sampling tubes filled with water saturated with carbon dioxide.

5. Mercury burette for gas sampling.

6. Filter pump and connections for exhausting air from container and pipes.

**

METHOD

The container and iron piping were first thoroughly cleaned t o remove any dirt or grease; and the inside of the container was given a thin coat of fire clay. Next, the specimen was placed inside of the container, and after having been tightly screwed together, the outside of the container was given a very heavy coating of fire clay. The container was then placed in the furnace with the outlet pipe leading through a hole in the door; and the heat started.

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After the furnace had been heated to 1600 degrees Fahrenheit for several hours, suction was applied to the outlet pipe of the container and the air exhausted for several minutes. Samples No. 1 and No. 2 were then taken.

Sample No. 1 was collected in a glass sampling bottle over water saturated with carbon dioxide. The gas came over at the rate of about 20 bubbles per minute, with the sampling bottle lying flat and the departing water creating no suction. There was sufficient gas pressure to fill the bottle when the exit of the tube was raised higher than the entrance.

Sample No. 2 was collected over Mercury shortly after No. 1 was taken.

Sample No. 3 was collected after the furnace had been up to 1600 degrees Fahrenheit for 6 hours, and up t o 1800 degrees for half an hour. The gas came over at a rapid rate and had considerable pressure behind it.

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III.

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Sample No. 1. **Collected over Water.**

Carbon dioxide	13.2%	
Hydrocarbons	0.0	
Oxygen	8.8	
Carbon monoxide	21.4	
By difference, N	56.6	100.0%

Sample No. 2 **Collected over Mercury.**

Carbon dioxide	13.2%	
Hydrocarbons	0.0	
Oxygen	8.8%	
Carbon monoxide	26.8%	
By difference, N	51.2	100.0%

Sample No. 3 **Collected over Water, Furnace at 1800 F.**

Carbon dioxide	4.6%	
Hydrocarbons	0.0	
Oxygen	3.4%	
Carbon monoxide	71.2%	
By difference, N	20.2	100.0%

Attention is called to the very high percent of Carbon Monoxide and the corresponding low percentages of Oxygen and Carbon Dioxide.

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From the results obtained in this experiment, the proof of the carbon leaving the casting in the form of a carbonaceous gas is established.

Both Sample No. 1 and #2 show this fact in their analyses, and are checked. The analysis of Sample #3 shows the presence of a very high percent of carbon monoxide, and a corresponding decrease in the amounts of oxygen and carbon dioxide. This is probably due to the fact that #3 was collected at a much faster rate and when the furnace was considerably hotter than for No. 1 and No. 2.

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GENERAL CONCLUSIONS, ETC.

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1. The nature of the packing does not affect the interior structure of the iron; while the surface or "skin" effect may vary from pure Ferrite to a Pearlitic Structure.

2. Packings like rolling mill scale and fire clay give as good results as any, and have the added advantage of being cheap. Of these two packings, fire clay would be the better because it packs closer and more effectively prevents access of the oxygen of the air to the specimen or casting.

3. Castings may be malleablized without the use of any packing, but a good muffle furnace should be used to cut down the oxidation of the casting's surface.

4. Air tight containers or those as nearly so as possible should be used to cut down oxidation effects.

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1. A temperature of 1550 to 1650 degrees Fahrenheit has proven to be best temperature to use for iron of the analysis previously given. This range insures a complete breaking down of the Carbide.

2. A temperature below 1400 degrees did not cause a complete breaking down of the Carbide structure; and even prolonged heating would not have produced a malleable structure at 1000 degrees Fahrenheit.

3. At temperatures of 1400 to 1500 degrees, there is danger in not getting a good malleable structure in those castings farthest from the source of heat and the furnace walls.

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TIME OF COOLING

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1. The time of cooling from the annealing temperature to 1300 degrees Fahrenheit, is t he most important variable in the process.

2. A rapid rate of cooling, even when sufficient heat and time of annealing is used, forms a Pearlitic or "steely" structure.

3. The time of cooling to 1250 degrees Fahrenheit should be about 42 hours. The cooling below this temperature may be rapid and not materially affect the malleable structure.

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TIME OF ANNEALING

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1. A period of from 36 to 42 hours gave the best results for this range of temperature.

2. An experiment not herein recorded showed that a good malleable structure could be obtained in 20 hours using a temperature of annealing of 1800 degrees.

3. The period of annealing is entirely dependent upon the temperature of annealing and the type of furnace used.

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CATALOGUE OF MICROGRAPHS

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Figure #1, X 100, etched with Picric Acid. Shows good interior structure of Ferrite and Temper Carbon.

Figure #2, X 100, etched with Picric Acid. Shows rim of pure Ferrite.

Figure #3, X 100, etched with Picric Acid. Shows an edge composed of Ferrite and Pearlite. (Steel)

Figure #4, X 100, etched with Picric Acid. Shows an interior structure of Ferrite, Temper Carbon and Pearlite.

Figure #5, X 100, etched with Picric Acid. Shows an edge carbonized; Bone Black used as a packing material.

Figure #6, X 100, etched with Picric Acid. Shows an interior structure of Ferrite, Temper Carbon and traces of Carbide.

Figure #7, X 100, etched with Picric Acid. Shows an interior white iron structure which is partially broken down.

Figure #8, X 100, etched with Picric Acid. Shows an edge of steel - Pearlitic structure.

Figure #9, X 100, etched with Picric. Shows interior of Ferrite, Temper Carbon & Pearlite.

Figure #10, X 100, etched with Picric. Shows an edge of very high carbon steel.

Figure #11, X 100, etched with Picric. Shows peculiar structure of double steel layer.

Figure #12, X 100, etched with Picric. Shows a heavy layer of Ferrite and then Pearlite.

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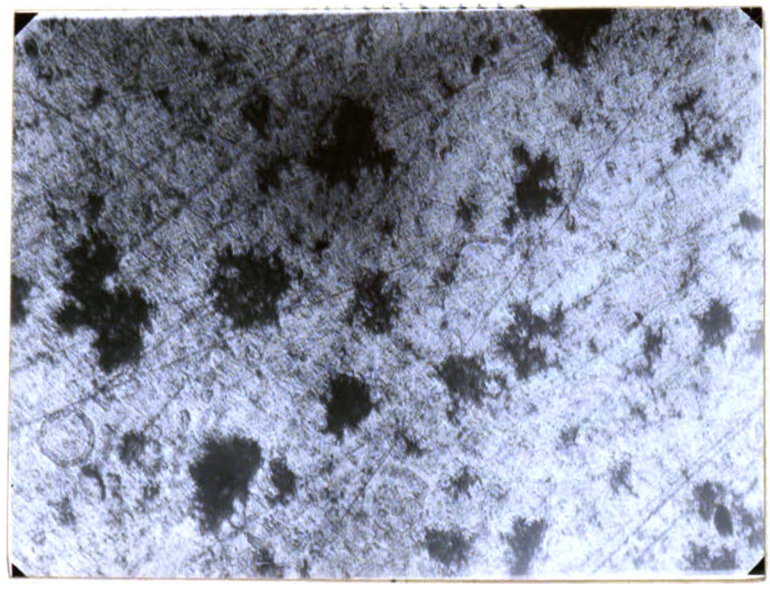

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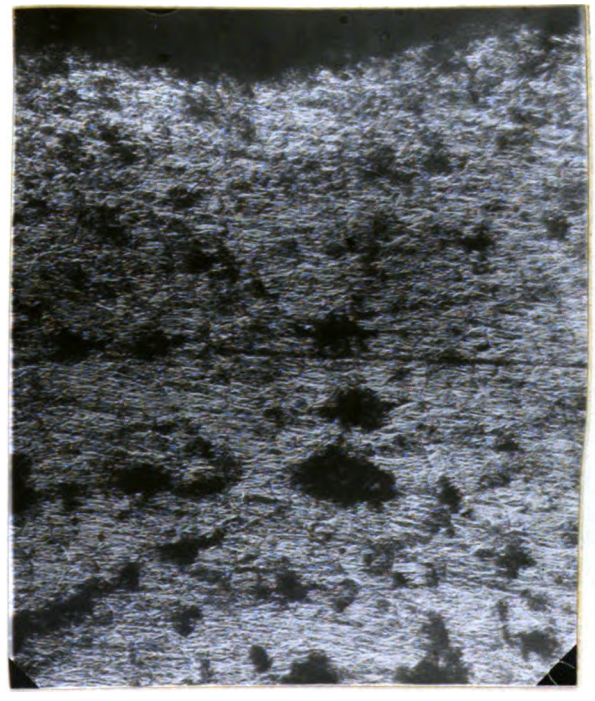

Figure No. 3.

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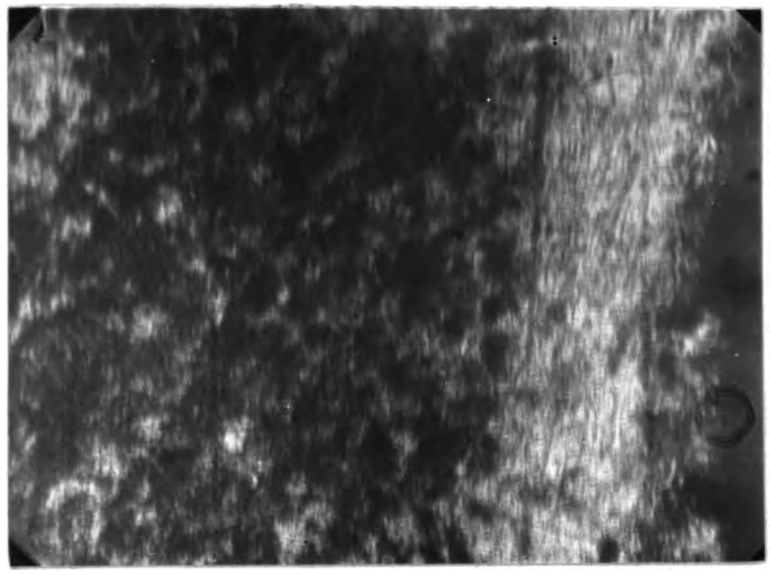

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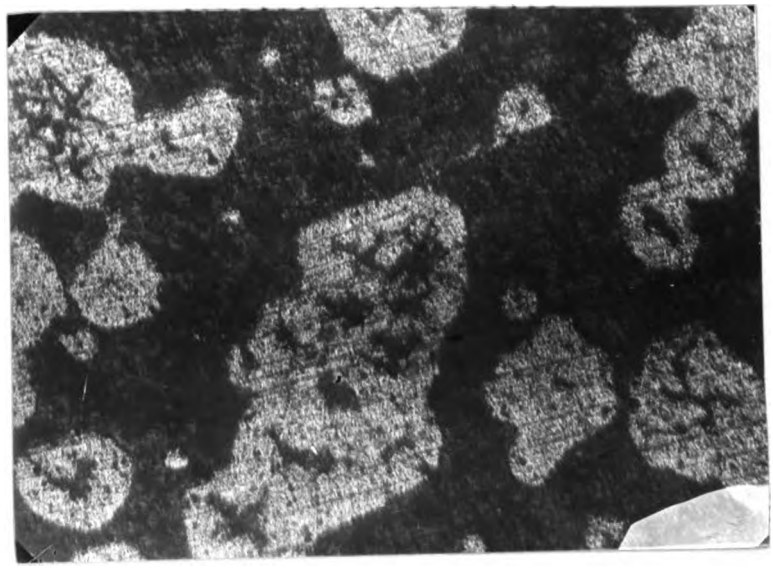

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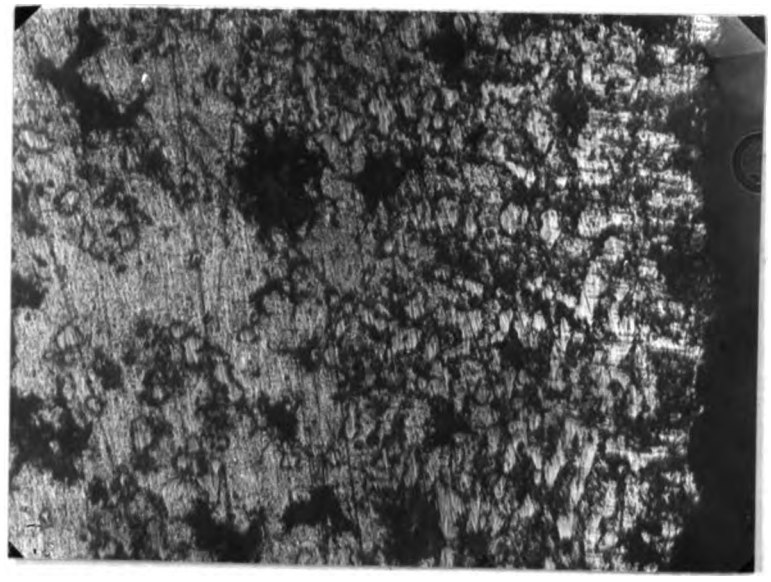

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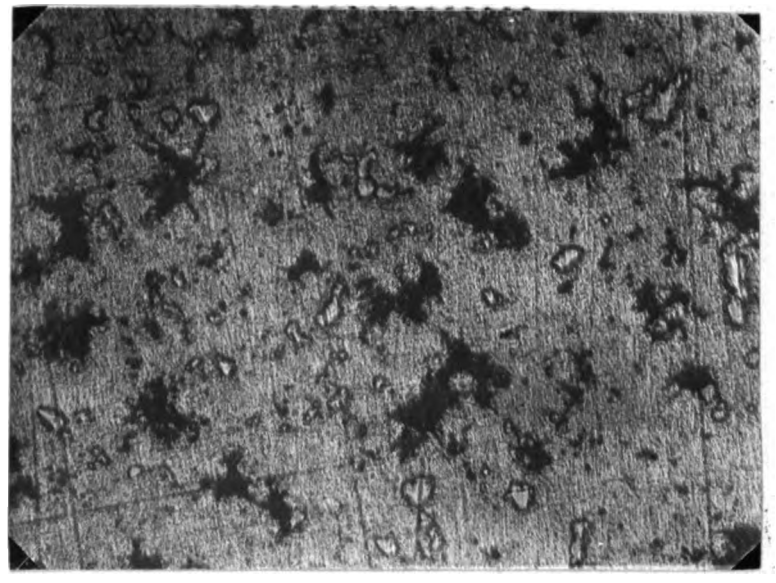

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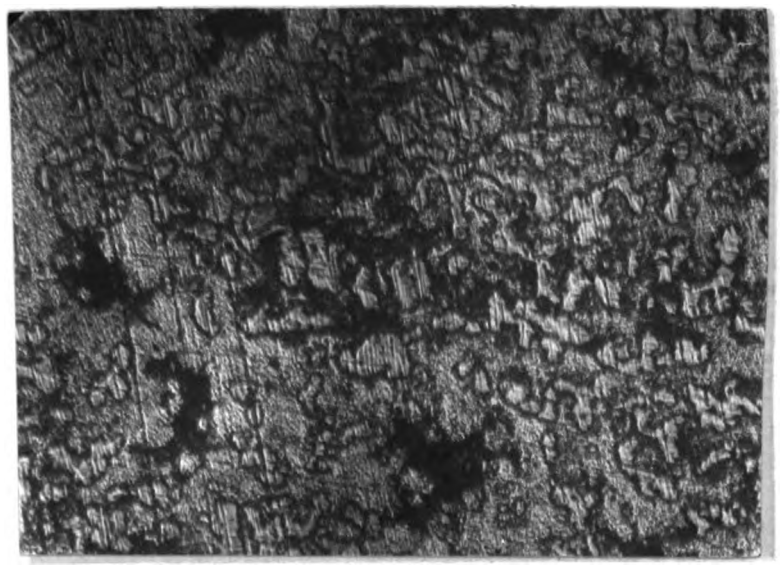

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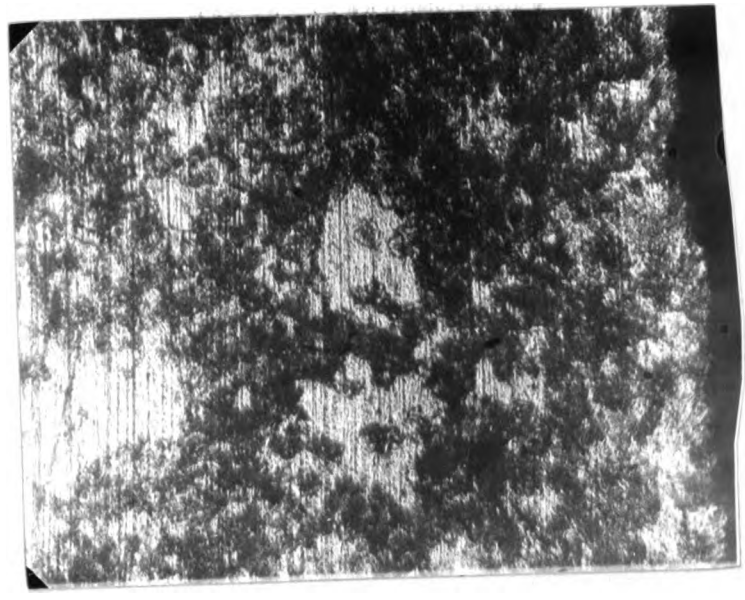

Figure No. 8.

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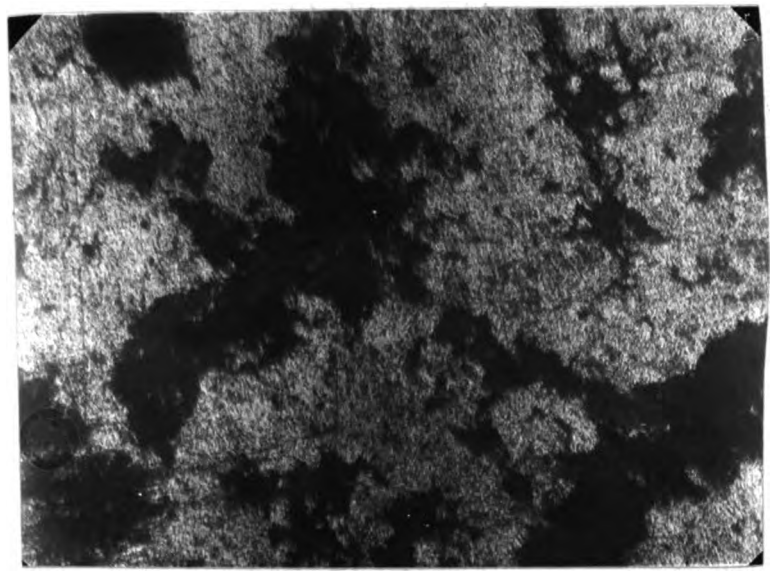

Figure No. 9.

Figure No. 10.

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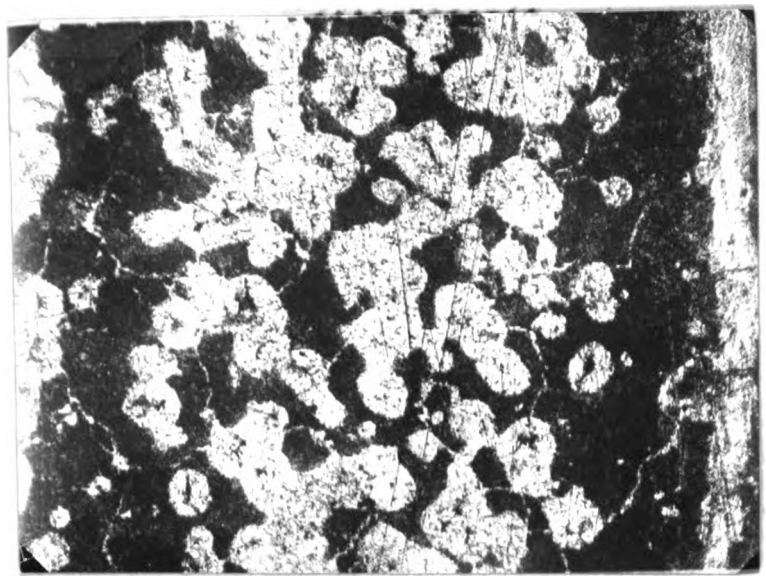

Figure No. 11.

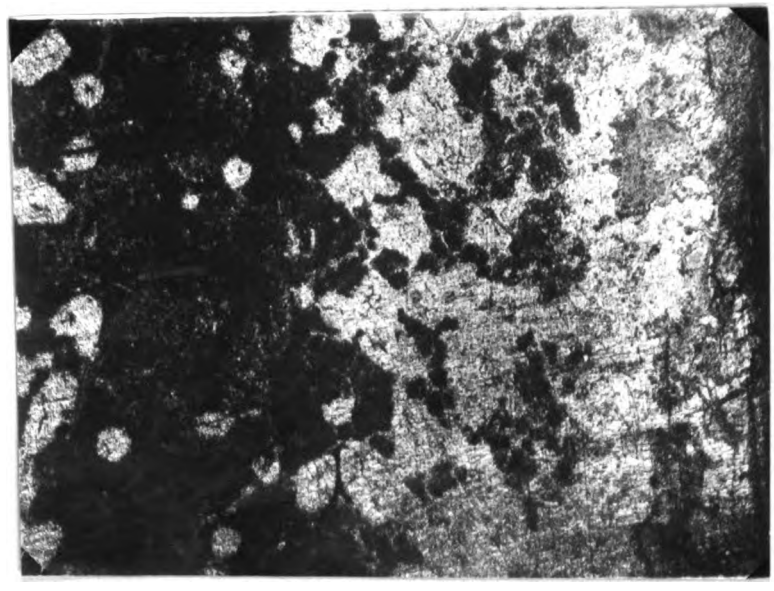

Figure No. 12.

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APPROVED

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COMMITTEE

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